Valleau & Johnson

Kentucky

Agricultural Experiment Station

University of Kentucky

TOBACCO FRENCHING—A NITROGEN DEFICIENCY DISEASE

BULLETIN NO. 281

(RESEARCH BULLETIN)

Lexington, Ky.

December, 1927.

EXPERIMENT STATION STAFF

Frank L. McVey, President

Thomas P. Cooper, Dean and Director

ADMINISTRATION

T. P. Cooper, Director
D. H. Peak, Business Agent
O. L. Ginocchio, Secretary

AGRONOMY

George Roberts, Head
E. J. Kinney, Assoc. Agronomist
P. E. Karraker, Asst. Agronomist
J. F. Freeman, Supt. Exp. Fields
W. D. Valleau, Plant Pathologist
E. N. Fergus, Asst. Agronomist
J. B. Kelley, Agricultural Engineer
E. M. Johnson, Asst. Plant Pathol.

ANIMAL HUSBANDRY GROUP

E. S. Good, Chairman
W. S. Anderson, Horses
L. J. Horlacher, Beef Cattle, Sheep
E. J. Wilford, Swine, Meats
W. J. Harris, Beef Cattle
J. Holmes Martin, Poultry
L. W. Taylor, Poultry
J. O. Barkman, Act'g in Charge Dairy Husbandry
J. W. Nutter, Dairyman
Amanda Harms, Asst. Path. Bact.
G. D. Buckner, Animal Nutrition
Harold Barber, Head Herdsman

ANIMAL PATHOLOGY

W. W. Dimock, Head, Vet. Science
Philip Edwards, Asst. Bacteriologist
F. E. Hull, Asst. Veterinarian

CHEMISTRY

J. S. McHargue, Acting Head
A. M. Peter, Chemist
S. D. Averitt, Chemist
O. M. Shedd, Chemist
W. D. Iler, Asst. Chemist
D. J. Healy, Bacteriology
E. S. Hill, Asst. Chemist

CREAMERY LICENSE SECTION

J. D. Foster, Inspector, in Charge
W. C. Eskew, Inspector

ENTOMOLOGY AND BOTANY

H. Garman, Head
Mary L. Didlake, Asst. Entomologist
H. H. Jewett, Research Asst. Entgst.
Jessie Terry, Seed Analyst
Lucille Dobbins, Seed Analyst

FARM ECONOMICS

W. D. Nicholls, Head
W. G. Finn, Farm Management
W. L. Rouse, Farm Management
R. E. Proctor, Farm Management
*Z. L. Galloway

FEED CONTROL

J. D. Turner, Head
H. D. Spears, Chemist
W. G. Terrell, Inspector
Fred Fitschen, Inspector
L. V. Amburgey, Microscopist

FERTILIZER CONTROL

H. E. Curtis, Head
Harry Allen, Chemist
Lelah Gault, Asst. Chemist
Robert Mathews, Inspector

HOME ECONOMICS

Mariel Hopkins, Head
Statie Erikson, Asst.

HORTICULTURE

C. W. Mathews, Head
A. J. Olney, Asst.
C. S. Waltman, Asst.

MARKETS AND RURAL FINANCE

O. B. Jesness, Head
Dana G. Card, Marketing
E. C. Johnson, Marketing
K. R. Zent, Marketing

PUBLIC SERVICE LABORATORY

L. A. Brown, Head
A. L. Meader, Asst. Chemist
James H. Martin, Asst. Chemist
E. K. Borman, Bacteriologist
O. H. Pinney, Asst. Bacteriologist

ROBINSON SUBSTATION

(Quicksand, Ky.)

R. W. Jones, Superintendent
C. H. Burrage, Forester
Lula Hale, Field Worker

WESTERN KY. SUBSTATION

(Princeton, Ky.)

S. J. Lowry, Superintendent

*Assigned by the U. S. Department of Agriculture.

CONTENTS.

BULLETIN NO. 281

(RESEARCH BULLETIN)

Tobacco Frenching—A Nitrogen Deficiency Disease

W. D. VALLEAU and E. M. JOHNSON

INTRODUCTION

Frenching of tobacco is a disease which has not been of much economic importance in Kentucky, but it is present to some extent every year and occasionally causes extensive injury to a promising crop. Altho it is occasionally of considerable economic importance to the tobacco grower, interest in a study of the disease at the present time lies in the fact that it is representative of one of the groups of chlorosis diseases which are now receiving much attention. A thoro understanding of the cause and control of one disease representative of a group of similar diseases in other crops, may have far-reaching effects in bringing about methods of control in them even tho the diseases, at first sight, may not appear to be closely related. The chief interest, in the opinion of the writers, in a study of frenching in tobacco will probably lie in the light which it may throw on apparently similar diseases of some of our tree crops, as the apple, pecan, citrus, and on certain other fruit and vegetable diseases, the causes of which have remained obscure.

The writers have had the disease under observation for some time, but only casually until the spring of 1925, when a considerable number of frenched tobacco plants developt in a plant bed on the Experiment Station farm. Assuming from the appearance of the disease in the field and in this bed, that it was a nutritional deficiency disease, attempts were made to control it in the plant bed by the addition of manganese compounds and

compounds of other elements sometimes thought to be essential for plant growth. The results were not particularly striking altho there was a suggestion of control following some of the treatments. Frenched plants from this bed, transferred to pots of sand in which a crop of corn had been grown, to which a complete nutrient solution had been added, were found to recover rapidly and then to french again.

No further work was done with the disease until the winter of 1925-26 when in growing Turkish tobacco plants for mosaic studies, they were found to french after they had attained a certain height. As this gave an opportunity to conduct studies on the control of the disease, these frenched plants were used for that purpose. It was later found to be a very simple matter, with the soil used, to develop any number of frenched plants, making it possible to conduct more extensive studies on the cause and control of the disease. The following paper reports the results obtained and a discussion of the relation of frenching to certain other obscure diseases of trees and vegetables.

METHODS

Turkish tobacco was used nearly exclusively for frenching studies in the greenhouse for the reason that the plants occupy less space than Burley and dark tobacco, while frenching symptoms appear as characteristically as on the larger leafed types. In previous work on root diseases of crop plants, especially corn and tobacco, it was found that soil from the Experiment Station farm or composted soil prepared for greenhouse benches usually produced very irregular lots of plants having extensive root injury. Soil from a forest on the Experiment Station farm however, produced uniform plants having no root lesions even on the smallest rootlets; consequently this soil has been used in preference to any other when it was desired to grow a uniform healthy lot of plants for mosaic studies or for other purposes. The soil used in the following studies has been obtained from nearly the same place in the forest each time. The upper layer of vegetation is first scraped off and then the soil for use is taken from a stratum four or five inches thick. The soil is a reddish

loam with a great deal of decayed organic matter mixed with it, making a black, loose, friable soil in which plants grow rapidly if a sufficient quantity is used. This soil will be referred to in the remainder of this paper as virgin soil. Glazed jars without drainage have been found to be preferable to the ordinary flower pots and so unless otherwise specified a pot or jar refers to a one-half gallon glazed earthernware jar.

Fig. 1.—Frenched Burley tobacco plants grown in a wet place in the field. The plants were removed to the greenhouse late in September when they were potted and photographed. Following transplanting to the pots they soon recovered altho no change of soil was made.

In the early studies when frenching developed unexpectedly in Turkish plants grown in this soil, the jars had been filled to within about an inch of the top but no record was kept of soil weight or moisture content when potted. In the later studies, moisture content, based on oven-dry soil, was determined and an equal weight of sieved and thoroly mixed soil was added to each pot. This had been found advisable in order to know more definitely the amount of nutrient material, in terms of oven-dry soil, applied to the soil in control experiments.

Turkish tobacco plants set in this soil in one-half gallon glazed jars have, with few exceptions, been found to french at some time during their development. It will be seen later that frenching occurs at quite a uniform time in a given lot of plants if an equal amount of soil is used in each pot and care is used in selecting plants of the same size. Plants set at intervals thruout the year have been found to french but at different heights. The size of the plant at which frenching occurs and the length of time required for frenching seem to depend on the season of the year in which the plants are grown. Unless otherwise specified, the term tobacco plant will refer to Turkish tobacco thruout this paper. The chemicals used in control experiments, unless otherwise specified, were C. P. (analyzed).

PRODUCTION OF FRENCHING IN THE GREENHOUSE

Frenching of Burley tobacco is quite common in the field and probably all the commonly grown types of commercial tobacco french when grown under conditions favorable to frenching. In the greenhouse, frenching has developt in Burley tobacco, in F_1 hybrids of Burley X *Nicotiana rustica* and in *N. rustica,* but the best success in producing frenching has been obtained with Turkish tobacco, possibly because it has been used more extensively than other tobaccos. The first Turkish plants which frenched in the greenhouse were a group of plants grown the winter of 1925-26 in one-half gallon jars of virgin soil. The plants made rapid and healthy growth in this soil until they reached a height of about 30 inches when all the plants frenched in rapid succession. When frenching commenced, the plants were showing some signs of nitrogen starvation as evidenced by the lower leaves turning yellow and in some cases dying. Since that time series after series of plants have been grown in this soil with the object of producing frenched plants for study, and in every series the disease has developt at about the expected time in the majority of plants. A few plants in a series may not dvelop the chlorotic condition in the leaves of the growing point, but they will always show other symptoms such as chlorosis and often death of the lower leaves and partial chlorosis

of all of the other leaves except those in the growing point. These symptoms (except the green growing point) are always associated with frenching of Turkish tobacco plants grown under the condition above referred to.

The question as to what soil conditions will cause frenching in the greenhouse cannot be answered at present. The virgin forest soil has nearly always given satisfactory results. Virgin soil heated to 65°C has never developed frenched plants in our tests, with one exception, even after marked signs of nitrogen starvation have appeared. Three untreated field soils from the Experiment Station farm failed to develop the disease, but in one of these (soil from a continuous corn plot unmanured) frenching developt but the symptoms lasted but a few days, when the plants showed the usual signs of nitrogen starvation.

The disease has developt in the greenhouse in sand cultures, using either Burley or Turkish tobacco. During the winter of 1925-26 Burley plants grown in sand frenched soon after showing signs of nitrogen deficiency in the lower leaves. Later a series of Turkish plants were started in sand cultures with the object of producing the disease. Twelve of fourteen plants developt frenching. This series will be referred to later.

Another method which has proved quite effective in developing frenching of either the mild chlorosis type or the more severe strap leafed type is that of cutting tobacco plants, which are making rapid growth but beginning to show signs of nitrogen starvation, back to three or four leaves. The new growth which develops from such plants usually will be frenched and often will have strap leaves (Fig. 3). This method has been successful with plants growing in virgin soil and in sand.

The disease has been produced by growing seedlings in a large jar of virgin soil in which they were badly crowded. *Nicotiana rustica* seedlings, under these conditions, frenched quite badly but it was only the smaller plants, the larger ones having a normal color.

Turkish tobacco plants set in glass tumblers of virgin soil have been found to french when only two or three inches high. This method of producing frenched plants for study has been

found to be very rapid and to give uniform results, especially if the plants are watered with distilled water (Fig. 7).

SYMPTOMS OF THE DISEASE

Frenching of tobacco is primarily a chlorosis of the tissue between the larger veins in the leaves of the growing point of the plant (Fig. 2). In the mildest cases chlorosis may appear only near the edges of the leaves. There are all gradations be-

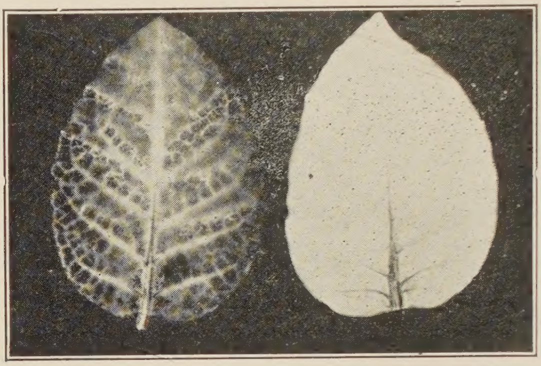

Fig. 2.—Prints of frenched and healthy Turkish tobacco leaves made directly on photographic paper. The reduced chlorophyl production is indicated by the extent to which the frenched leaf (left) has allowed the light to pass thru it.

tween this condition and one in which but little besides the mid-vein develops, the blade being either improperly developt in its early stages or unable to expand properly (Fig. 3). As the leaves of a frenched plant develop they may show only slight chlorosis or more extensive chlorosis with the blade expanding normally for a time but soon being outgrown by the mid-vein, resulting either in the blade tearing to allow for more rapid development of the mid-vein (Fig. 4A) or the leaf bending, hooking the mid-vein down and back, thus forming a cup of the under side of the leaf (Fig. 9). This occasionally happens in the greenhouse with Turkish plants, but is a common symptom in rapidly growing frenching tobacco in the field, giving a peculiar picture in which there is a whorl of rapidly developing leaves at the top of the plant, each appearing very light colored

and each hooked sharply down and back near the tip. This condition is not always found but is not uncommon in frenched Burley. More severe cases of chlorosis, in which no coloring matter develops in the blade, usually result in strap leaves. Altho these leaves are at first chlorotic, in the field they gradually develop a dark green color and a badly frenched plant with ribbon like leaves may, under certain conditions, lose all signs of chlorosis. Occasionally frenched plants growing in the field produce a succession of narrow strap leaves exceeding the normal number of leaves produced by the variety. Frenching may appear at any stage of growth. It has been observed several times in plant beds, but in a mild form, where the plants are crowded and growing rapidly. Plants set in the field sometimes french as soon as growth commences and either remain frenched (narrow leaved but normal color) thruout the summer or become normal in a short time and continue healthy thruout the remainder of the season. One instance in which Burley plants remained frenched (strap leafed) the entire season was observed where they were set in rich soil close to a tree. The tobacco away from the tree made excellent growth. Plants making rapid, apparently normal growth, may french at any height. One instance was seen in which rapidly growing Burley plants five feet tall frenched, the frenched growth resulting in chlorotic leaves only a few inches long while below the frenched area the leaves were normal in length and width and very dark green. Chlorosis of the growing point is usually a temporary condition in the field, the frenched leaves taking on a dark green color as soon as the immediate conditions which bring about the disease are changed.

In the greenhouse the disease of the growing point is usually associated with chlorosis of the lower leaves indicating nitrogen starvation. In the field we have not observed this relationship, and it probably does not often occur. Frenching very often develops in suckers in the fall after the tobacco has been topped, in plants which have appeared healthy thruout the sum-

Fig. 3.—A. B. Showing the effect of nitrate on Turkish tobacco plants cut back. Both plants were frenched at a height of 30 inches, when cut back on August 30, 1926. Plant A received no further treatment while plant B received, when cut back, 30 cc. of a sodium nitrate solution containing 25 grams per liter. Photographed Sept. 21, 1926.

C. Frenching in Burley tobacco produced by cutting back. The plant was growing in sand to which a nutrient solution had been added. When showing signs of nitrogen starvation it was cut back to three leaves (Jan. 18, 1926). Photographed Feb. 16, 1926.

mer. In our limited observations of the disease in the field the chlorotic stage appears to develop more commonly when conditions are optimum for rapid growth; that is, after a rainy period, when temperature and humidity are high. Probably for this reason the disease has received the name of "wet weather frenching" in contrast to mosaic which is commonly called frenching or dry weather french in Kentucky.

SOIL RELATIONS

There appears to be no easily observed constant condition in the soil correlated with frenching of tobacco. It occurs in areas of the State having predominantly acid soil and is common in the Bluegrass section where the soil is only slightly acid. It occurs most commonly in areas which appear to lack proper drainage. On the other hand, plant beds in which mild cases of the disease have been seen were not in areas lacking drainage. The frenched plants mentioned previously as growing under trees were not in a wet soil and one quite severe case was observed on a portion of a well-drained hillside, in tobacco about half grown. The owner of this land stated that it was a piece of land which he could work early in the spring and soon after rains. The only observed difference in the land in which frenching occurred and the land farther down the hill in which plants were healthy was that the upper portion of the hill was next to a limestone road from which it received much lime dust and as
some by washing. In an adjacent meadow in which the same condition obtained, sweet clover grew down the hill as far as frenching occurred in the tobacco field, suggesting a relation between the amount of lime in the soil and frenching, in this particular case. Frenching also occurred on a level piece of land, at the foot of this hill, which received wash from several directions and probably was wet for a longer time after rains. The conditions under which frenching occurs in the greenhouse indicate that the relationship between Frenching and the soil is primarily one of nitrogen deficiency.

LITERATURE

The literature on frenching is quite limited. The disease has been recognized as being related to soil conditions but little has been written as to the cause or control of it.

Clinton, (4) in describing inoculation experiments with tobacco mosaic, states (Exp. 188), "Juice was used from peculiar malformed leaves of 'string leaf' disease . . . These plants had the color of suppressed calico, but other similar plants kept in crocks in the greenhouse for a time regained their normal color." No infection occurred in fifteen plants inoculated except in one "probably from original unknown infection." He states further (p. 411), "String leaf is a malformation of the leaves that sometimes accompanies calico, but is not dependent upon a calicoed condition of the plant for its development." These were probably frenched plants as they were both chlorotic and narrow leafed.

Wolf and Moss (24), discussing frenching, state: "The cause of the disease is unknown. It is not infectious, however, since all efforts to communicate it to healthy plants have failed. . . . Excessive soil moisture, due to a wet season, proximity to the water table, to ditches, to stumps, or to small basins where the water may collect is very commonly associated with the disorder. . . . It has been noted on the tobacco experiment farm at Oxford, N. C., that on certain plats, which had received no fertilizer, practically all of the plants were frenched. Here no cause other than the mineral deficiency could be found, since all plants on adjacent plats remained normal. . . . It is of interest to note that under experimental conditions, affected plants, when transplanted, have been made to recover."

Garner (6) states: "This disease is not infectious and is due to some unfavorable condition of the soil. . . . The disease may occur at any stage of development, and often only the upper part of the plant is affected. Defective drainage is a frequent cause of the disease and it appears that deficiencies in plant

food may cause symptoms of the trouble. Correction of the cause of the trouble often leads to the recovery of the plants."

Johnson (8) states: "The actual cause of frenching is not yet known . . . although a number of predisposing factors have been observed, the production of this disease at will, as far as known, has not been repeatedly accomplished. . . . The disease is frequently found on soils exposed in one way or another to excessive water. This together with its occurrence at times on portions of fields in poor tilth, indicates a relation to soil aeration. On the other hand, frenching seems to have considerable relation to soil fertility, or at least to a deficiency of certain fertilizing elements, but in combination with these factors certain weather conditions must apparently exist to bring about its expression."

SIMILAR DISEASES OF OTHER PLANTS

The rosette diseases of apples and pecans appear to be very similar to tobacco frenching. This is brought out in figures 2, 5 and 7 in the publication on "Apple Rosette" by O. M. Morris (13), in which are presented photographs of apple shoots showing normal leaves on the lower portion of the current season's growth surmounted by a cluster of narrow strap shaped chlorotic leaves at the tip of the shoot; and in plates I and III in the paper by Rand (15) on Pecan Rosette and in Plate XXIV in the paper by Orton and Rand (14) on Pecan Rosette, in which are shown the chlorotic strap leaves common to the three diseases. The descriptions of the diseases correspond very closely to tobacco frenching as will be pointed out later. These diseases have been attributed to various causes, as lack of moisture or to improper nutrition, the bulk of evidence indicating that the diseases are of non-parasitic origin. However, after a histological and cytological study of the pecan disease, Rand concludes that it "is much more in agreement with the infectious type of chloroses, including the yellows and mosaic groups, than with those chloroses known to be caused directly by soil or climatic conditions." He, however, leaves the question as to cause entirely open. Morris considers apple rosette to be

"a functional or nutritional disorder." McMurran (11) studied pecan rosette from the standpoint of the natural distribution of trees, which were nearly always healthy in nature, and the distribution of diseased trees in commercial plantings and concluded that "The facts pointed very strongly to the rosetting of pecans being an evidence of bad soil conditions—a deficiency of humus, fertility, and moisture supply." Skinner and Demaree, (17) continuing this work on pecan rosette, studied the relation between soil conditions and pecan rosette in orchards under different systems of management, and concluded "There is a close correlation in these orchard soils having a high nitrogen and organic matter content with the healthy, productive trees and soils having a low nitrogen and organic matter content with unfruitful rosetted trees."

In both apple and pecan rosette it is reported that marked results have been obtained by plowing under or disking in cover crops, especially legumes, or by simply growing alfalfa in the orchard (3). Further consideration will be given to the similarity between these two diseases and tobacco frenching later in this paper. There is a marked similarity between the diseases of citrus trees, apparently induced by ground limestone, described by Floyd (5) in Florida, and the above diseases. The conditions under which the disease develops seem to correlate well with those under which pecan and apple rosette develops; that is in soils with low organic matter, where if lime is added growth may apparently be stimulated for a time, but eventually the disease develops. The addition of manure, with the resultant better development of legumes, gradually results in control of this disease also. The similarity between the conditions under which these diseases develop and the conditions under which tobacco frenching develops may not at first be apparent. However, when frenching develops in pots the relationship becomes much more evident.

It is probable that chlorosis diseases of other plants will be recognized as due to the same causes which produce tobacco frenching, as soon as this disease is better understood. The chlorosis of the new leaves of corn which quite commonly develops

following rainy periods in certain soil areas, in corn which is growing very rapidly, is a chlorosis probably belonging to this group altho it is only a temporary condition which is more than likely to escape other than casual notice.

Following the Florida hurricane on September 20, 1926, many trees were badly injured and were severely cut back. The senior author visited the storm area about Miami early in November when many of the injured trees were developing new shoots. Conditions very similar to those found in early stages of frenched tobacco were observed. Chlorosis of the new shoots of grapefruit was common on trees on which the older leaves were dark green, reminding one very much of the condition found in mild cases of frenching of tobacco. Many avocado trees were severely injured leaving little beside the trunk and some of the heavier branches. The new growth on these trees was chlorotic, altho often of a deep purple color, and one tree was found on which the leaves were hooked back in exactly the same way as severely frenched tobacco leaves. The soil in which these trees were growing was largely calcareous and low in organic matter so that it would be expected that rapidly growing shoots resulting largely from stored carbohydrates might show nitrogen deficiency troubles. Whether the condition observed in citrus was the same as that described by Floyd cannot be stated but it appeared quite similar.

EXPERIMENTAL STUDIES

In the fall of 1925 an attempt was made to produce frenching in Burley plants by growing them in pots of soil collected from a plant bed where frenching had been extensive the spring before. The plants made very poor growth and did not french. Soon after this a few Burley plants which had been growing in sand, and had been cut back to a few leaves, frenched, giving an opportunity to attempt control. When these plants frenched they exhibited signs of nitrogen starvation as indicated by the lower leaves turning yellow (Fig. 3c). In the plant-bed experiments the previous spring there was a suggestion that potassium iodide improved frenched plants. This and sodium borate were added to certain plants but no effects were noticed. As the

plants were showing nitrogen deficiency, 40 cc. of a potassium nitrate solution (25 g. per liter) were added to one pot and 40 cc. of sodium nitrate solution similarly prepared, to another. Both plants recovered from frenching. At about the same time a few Turkish tobacco plants growing in one-half gallon jars of virgin soil were frenching at a height of about 38 inches. These likewise showed nitrogen deficiency in the lower leaves. To one of these was added a potassium iodide solution followed in about a week with 40 cc. of a calcium nitrate solution (25 g. per liter) and to another, 20 cc. of a "complete" nutrient. In nine days the growing point of each was normal altho in the latter a few old leaves still showed a slight chlorotic pattern. The rapid recovery following the addition of materials containing nitrogen suggested that the problem was one concerned with this element. Consequently several other plants which frenched were given available nitrogen and the results were always the same; namely, rapid recovery as soon as sufficient nitrogen had been added. Following these preliminary trials other studies were conducted which gave more conclusive proof that frenching in tobacco is due to nitrogen deficiency in the frenching tissue. These experiments will be described in the following pages.

RECOVERY OF FRENCHED PLANTS

Natural Recovery. If Turkish plants growing in half gallon jars are cut off to a few leaves they will often french. If the plants have been growing normally and have shown no signs of nitrogen deficiency, it is probable that the suckers which develop will be normal. If, however, the plants have begun to show nitrogen deficiency, even tho they have not yet frenched, the new growth, as it develops, is almost certain to be frenched, showing chlorosis or both chlorosis and the strap leaves. Evidently what has happened is that a plant with a store of carbohydrates has been put in the position of having to produce new shoots from stored food in the absence of a readily available source of nitrogen. By using the stored carbohydrates the plant

rapidly produces new tissue, but is incapable of elaborating chlorophyl and other compounds necessary to normal cells, in the absence of a readily available supply of nitrogen. As a consequence, the leaf, if it expands, appears chlorotic or if the cells are not sufficiently supplied with the necessary constituents to expand, the tissues develop to some extent about the mid-vein and a strap leaf results (Fig. 3). A plant of this kind, once it has used up its stored carbohydrates, elaborates them slowly, due to a reduced, chlorotic leaf area, and consequently has a small demand for nitrogen. Under these conditions it may lose all symptoms of frenching (as evidenced by a chlorotic growing point or the production of strap leaves) and assume the appearance of a plant showing typical nitrogen starvation; that is, a general chlorosis. The plant has evidently adjusted its growth to the available supply of nitrogen in the absence of a large leaf surface which could produce carbohydrates faster than nitrogen is available for normal growth. Recovery of normal color by frenched plants in the field, whether the leaves are strap shaped or nearly normal in shape, is quite common.

Plants that have developt slight frenching in the course of their growth in pots quite often recover completely from symptoms of frenching and may not regain them. Recovery of these plants may be of two apparent kinds. The plant may, due to particularly favorable growing conditions, make very rapid growth for a few days and as the conditions for growth become poorer (reduced light for example) it may again be able to obtain nitrogen as rapidly as growth progresses and recovers. Other plants may french as nitrogen becomes deficient slowing down growth until it nearly ceases, when they may lose growing point symptoms of frenching but show marked symptoms of nitrogen starvation.

Another type of recovery in which the individual leaves recover while the growing point continues to french has been observed in several cases. A striking example was that of a small plant growing in a gallon pot of virgin soil with a large plant. The large plant was cut off at the soil February 8, 1926. The small plant then made quite rapid growth and frenched March

22. A month later it was seventeen inches high with the growing point still frenched, but with 22 healthy leaves which, except for the lower ones, had begun as frenched leaves, but had recovered as growth progressed. The plant was evidently growing slightly ahead of the available nitrogen supply, but available nitrogen compounds were being produced rapidly enough so that the frenched leaves gradually obtained enough to take on a healthy green color and assist in the production of carbohydrates necessary to terminal growth. It is important to note that the leaves some distance back from the growing point were supplied with the necessary material before those higher up on the plant, and thus the healthy zone of leaves gradually pushed higher on the plant as long as nitrogen was available. This point will be given further consideration when discussing certain physiological diseases of fruits. By May 10 the plant was evidently growing more rapidly than nitrogen could be obtained, as eleven leaves at the top were frenched while the balance of the leaves were showing nitrogen deficiency. On May 26 the bud leaves were very narrow and were becoming necrotic (Fig. 4A), when the plant was given 150 cc. of a KNO_3 solution containing 25g. per liter. On June 5, 100 cc. more of the nitrate solution was added. Following the second addition, the plant began rapid growth, producing a number of suckers from the leaf axils, all of which were frenched. In another six days the new growth was healthy in appearance and dark green while the old leaves were still frenched (Fig. 4B). Later the old leaves recovered a normal color. The plant was discarded July 7, at which time it was growing rapidly and had a very dark green color.

Recovery of Grafted Tips. Since it had been determined that the addition of nitrate to the soil would rapidly bring about the disappearance of frenching symptoms, it was believed that if frenched tips were grafted on healthy plants they should recover their normal green color. Grafts were made on three occasions and in each case the frenched tips recovered. One case only will be described. On February 23, 1926, a frenched tip of Turkish tobacco was grafted on one branch of a Turkish plant

Fig. 4.—Turkish tobacco plant before and after the addition of nitrate. A. This plant was growing as a seedling in a gallon jar of virgin soil with a large plant. The latter was removed Feb. 8, 1926. The smaller plant grew rapidly and frenched March 22. On April 20 it was 17 inches high, the growing point still being frenched, but the older leaves had recovered, one by one. On May 10 the top eleven leaves were frenched and the lower leaves were beginning to show nitrogen starvation. It was photographed May 26, at which time necrotic spots were present in the small leaves. On this date 150 cc. of a KNO_3 solution (25 g. per liter) was added, and on June 5, 100 cc. more was added. B. The same plant June 22, a few leaves having been removed to show the original frenched growing point.

which had developt two growing points. A cleft graft wrapped with moist cotton and waxed paper was used. On March 10 the frenched tips appeared to be recovering; March 13 the tip growth on the ungrafted branch developt frenching, and 40 cc. of a potassium nitrate solution was added. In nine days both the frenched graft and the growing point of the other branch had recovered completely. It might be said in this case that the grafting of a frenched tip to a healthy plant had introduced the disease, which then appeared in the other growing point. This position might be tenable were it not for the fact that numerous other plants not grafted have developt frenching at about the same stage as this one and have recovered in all cases upon the addition of available nitrogen. Wolf and Lehman (23) grafted frenched buds on healthy stocks with no evidence of transmission of the disease.

Recovery in Tap Water. On February 23, 1926, a frenched and a healthy tip of Turkish tobacco were placed in flasks of tap water to see whether recovery would result. The tap water contained naturally a trace of nitrate. The water was changed at about weekly intervals. In 12 days roots had begun to develop on the cuttings and in 16 days the frenched cutting was showing signs of recovery and was fully recovered in 24 days. Both cuttings continued to develop, blossomed and ripened seed. There was some question as to whether the frenched plant had actually obtained its necessary nitrogen from the water or by translocation from its lower leaves. Both of these plants made slow growth and were light green, indicating a lack of sufficient nitrogen.

Recovery of Frenched Cuttings due to Calcium Nitrate. Two frenched cuttings were placed in two 1500cc. Erlenmeyer flasks, one of which contained a solution made by adding 4.6cc. of concentrated nitric acid and 6 grams of U. S. P. precipitated calcium carbonate, per liter of distilled water. There was an excess of .7 grams of calcium carbonate per liter over that necessary to neutralize the acid. The other flask contained only distilled water to which was added this excess of calcium carbonate.

The experiment was started March 24, 1926. In 5 days the leaves of the plant in the solution containing the nitrate were be-

coming green and in eight days recovery was nearly complete. In 15 days there remained no indication of frenching. The entire cutting had a healthy green color. The cutting in the calcium carbonate showed signs of new growth recovering in eight days but at that time the lower leaves were turning yellow, suggesting that recovery was at the expense of the lower leaves thru translocation. Later the whole cutting became lemon yellow, a different color from that ordinarily produced by nitrogen deficiency.

Recovery Due to Addition of Fresh Soil. A Turkish tobacco plant set in a one-half gallon jar of virgin soil December 28, 1925, had developt 29 full-grown leaves by February 8, 1926. At this time the growing point and two of the full-grown leaves were frenched. The plant was cut back to about four leaves. Three suckers developt, all of which were severely frenched. On February 19, the soil was removed from the pot without disturbing the roots and set in a gallon jar, fresh soil being placed about it. On March 2 the new growth showed no signs of the disease and four days later the older leaves had recovered completely. This plant grew rapidly until the flowering period. It was kept until June 16, 1926, at which time neither it nor a plant growing in the same pot, which had attained a height of eighteen inches, showed signs of frenching.

Recovery Due to the Addition of Leachings. Two plants were set on February 8, 1926, and were frenched April 15. On that date a leaching tube was filled with virgin soil, the delivery end being placed just above the surface of the soil in the pot. The plants were watered thru the leaching tube and thus received the soluble material from the soil. On May 12 the two plants had recovered completely. The soil had been changed in the tube three times during this period. Check plants in another pot watered with tap water remained frenched. A month later the check was still frenched and the plants which had received leachings were healthy.

SOIL CONDITIONS AND FRENCHING

Effect of Standing, Without Crop on Soil Which had Produced Frenched Plants. During the course of these investiga-

tions it has been noticed that plants may recover partially or completely in soil receiving no treatment if there has been an opportunity for the soil to apparently build up an available supply of nitrogen faster than it is taken up by the plant. For example, small seedling plants were set in pots in which a single large plant of tobacco was growing. This was done previous to frenching of the large plant. When the large plant frenched the small plant usually developt the disease also (Fig. 5). In several cases the large plant was cut back below the lowest bud so that it was destroyed. Under these conditions the soil would contain relatively few active roots. The result was that the small plant usually recovered in the course of a few days and re-

Fig. 5.—Small Turkish tobacco plants growing in a pot with a large plant. The small plants both frenched at the same time as the large plant, and recovered with the large plant following the application of nitrate to the soil.

mained healthy for a considerable period. In some instances where the small plant was well established when the large plant was destroyed it did not recover but continued frenched in the growing point, the older leaves gradually recovering.

In order to determine the effect of allowing soil, which had already produced frenched plants, to stand for a time without crop under good conditions for biological activity, soil was removed from pots in which frenched plants had developt; it was sieved and placed in a four-gallon jar on March 26, 1926, where it remained for six days. It was then put into six one-half gallon jars, an equal amount being put into each jar. The moisture content was determined. Two of the jars received no other treatment. To two were added 40 cc. of a nutrient solution containing no nitrate.[1] Two pots received the nutrient solution, as above, together with 320 ppm. of NO_3 in the form of KNO_3. Two other pots were filled with an equal amount of fresh virgin soil from the same place in the woods from which the original soil was obtained. One small Turkish plant was set in each pot April 1, 1926. The plants all developt normally for a time, with a dark green color and no signs of frenching. The plants in "frenched" soil developt at about the same rate as those in virgin soil at first but gradually became larger. Those receiving nutrients grew faster than either of these; while those with nitrate added made much more rapid growth than the others (Fig. 6A). Frenching appeared first in the plants growing virgin soil (36 and 40 days); next in the plants in untreated "frenched" soil (43 and 46 days), while those receiving nutrients without nitrate frenched in 47 and 49 days. The plants receiving nutrients plus 320 ppm. of NO_3 showed no signs of frenching altho kept for ninety-two days. The results indicate that soil which has produced frenched plants readily regains its ability to produce healthy ones if allowed to stand for a time and may be in actually better condition to produce a healthy plant than the original virgin soil. This experiment has been

---

[1] The solution contained 25g. $MgSO_4,7H_2O$, 25g. KH_2PO_4, .5g. $MnSO_4$, $4H_2O$, .5g. $FePO_4$ and .25g. $CuSO_45H_2O$ per liter.

Fig. 6.—A. Showing the ability of soil which has produced a frenched plant to produce a healthy plant. 1, 2, 3, Turkish tobacco plants growing in soil which had previously produced frenched plants in pots. The soil from several pots was mixed and allowed to stand 6 days, repotted and plants set. 1 "frenched" soil with no treatment; 2 "frenched" soil with complete nutrient, minus nitrate; 3 "frenched" soil plus complete nutrient, including nitrate; 4 virgin soil in which tobacco had not previously been grown. When photographed May 29, all but 3 and its mate were frenched. The plants to which nitrate had been added did not french.

B. The effect of lime on the growth and frenching of Turkish tobacco in virgin soil. 1. CaO added to the soil at the rate of 10,000 ppm. of oven dry soil. The growing points of the plants are normal and the lower leaves are alive altho somewhat chlorotic. 2. Virgin soil untreated; the growing points are severely frenched and the lower leaves are dying.

repeated several times with comparable results. The addition of sufficient nitrate evidently prevents the development of the disease. The addition of a nutrient solution minus nitrate increased the growth of the plants somewhat over those not receiving it and slightly delayed the time of development of frenching. Further tests using a nutrient solution[2] without nitrogen again demonstrated that the addition of other plant foods than nitrate to this soil had but little effect on the growth of tobacco plants if nitrogen is not available, and had no apparent influence on frenched plants.

The Effect of Packing Soil. A series of Turkish plants were grown in glass tumblers in virgin soil. One of these developt frenching soon after it started while the others appeared to grow normally. The physical condition of the soil in this tumbler seemed to be poorer than in the others, appearing to be packed more. To determine whether packing might be a factor in bringing about the conditions which result in frenching, a set of four plants was started in tumblers. The soil in two was packed as solidly as possible with the hands and the plants set in some looser dirt put over the packed soil. The other two plants were put into soil settled as it usually is in potting work by slight pressure and jarring. The plants were set March 31, 1926. On April 27 and 28 the plants in the loose soil frenched and four days later the plants in the packed soil frenched. Sixty-six days later the four plants were still frenched, having made only slight growth in that time. On that date 30 cc. of a KNO_3 solution containing 25 g. per liter was added to one of each set. Six days later these two plants were free from frenching and had resumed growth. The nitrate added was sufficient to bring the plants to flowering at a height of 35 inches, at which time the untreated plants were still only six and seven inches high respectively. The progress of control in a similar plant following the addition of nitrate is shown in Fig. 7. Packing the soil in this and in one other test appeared to have no influence on the development of frenching except possibly to delay it slightly, probably due to the fact that more soil was

[2] 25 g. KH_2PO_4, 25 g. $MgSO_4,7H_2O$, .5 g. $MnSO_4,4H_3O$, .5 g. $FePO_4$, .25 g. $CuSO_4,5H_{20}$. Distilled water 1000 cc.

Fig. 7.—The progressive stages in control of frenching by the addition of available nitrogen. The plant was set in virgin soil February 11. It frenched on March 24, (A) on which date nitrate was added. B shows partial recovery 21 days later and C complete recovery after 43 days.

introduced. The other two plants were kept throut the summer but were given no particular care, being dry much of the time. They made practically no growth. On October 5, one of them was given 15 cc. of $(NH_4)_2SO_4$ solution (19.5 grams per liter) and a second application was given a few days later. The plants were photographed December 10 (Fig. 8A), at which time the

treated plant was growing rapidly while the other had a small rosette of light green leaves surmounting a stalk bearing dead leaves. The similarity of the latter condition to that commonly attributed to drouth will be given further consideration in connection with apple rosette.

THE RELATION OF SEASON TO FRENCHING OF TOBACCO IN POT CULTURES

In these studies it has been observed that plants grown during the winter usually attained a much larger size and required a longer period of time before frenching occurred than at other seasons of the year. This may be illustrated by two groups of plants, one lot of which was set in one-half gallon jars of virgin soil on December 10, 1926, and the other the following June. Records were kept on only twelve of the first lot of plants but they were representative of a much larger group. These plants frenched at an average height of thirty-eight inches, after having produced an average of 29.5 leaves. The first plant frenched 59 days after setting and the last in 74 days. In contrast with these were a group of forty plants started under the same conditions except that they were potted on June 5, 1926. In thirty days frenching appeared in four plants, in another 10 days 30 plants were frenched, and eleven days later four more were frenched, while the remaining six did not french, altho they showed marked signs of nitrogen starvation. The average height of the plants when they frenched was 14.5 inches with an average of 13.1 leaves per plant. (Table 1).

Other striking differences in the time required for plants to french in the winter and summer, in which two and three plants per pot were used instead of one, are presented in Table 1. Considering the fact that the same type of soil was used during the winter and summer and the type of disease being dealt with is a deficiency trouble, it seems evident that the limiting factor is an unstable material depending for its availability on immediate conditions affecting the soil. This in itself would tend to rule out the possibility that the disease was due to deficiency of a mineral plant food which might be carried as an impurity in the chemical sources of nitrogen which have been found to bring about control, and makes it more certain that the available

TABLE 1.—Showing the Relation Between Season, and Size and Time of Frenching of Turkish Tobacco Plants Growing in Virgin Soil in One-half Gallon Jars, in the Greenhouse.

Date Set	Date Frenched	Days to French	Average Height of Plants which Frenched. Inches	Average No. of Leaves When Frenched	Number of Plants
	One plant per pot.				
Dec. 10 1925	Feb. 8-23 1926	59–74	38	29.5	12
1926					
June 5	July 3	30	12.4	11.7	4
June 5	July 6, 7, 8	31–33	14.0	11.8	11
June 5	July 9	34	13.7	13.0	9
June 5	July 12–15	37–40	15.6	13.7	6
June 5	July 26	51	17.7	17.7	4
	Average		14.5	13.1	34
	Two plants per pot.				
1926					
Apr. 22	May 28–31	36–39	7.6	8.2	6
Nov. 2	Dec. 15-29	43–57	12.3	13.2	20
	Three plants per pot.				
1926					
Feb. 8	Apr. 14–19	65–70	14.0		45
Apr. 22	May 27–28	35-36	5.9	6.8	9
Nov. 2	Dec. 18-29	46–57	10.7	11.3	57

nitrogen supply itself is the important factor in the problem. The factors concerned in the difference in time required for frenching in winter and summer have not been determined, altho it is surmised that slower growth during the winter gives a longer period during which nitrates may be made available for a given unit of growth.

Figure 8.—A. The effect of the addition of nitrogen to a plant showing marked signs of nitrogen starvation. The two plants were set March 31, 1926, frenched May 2 and April 27, respectively, and stood in the greenhouse thruout the summer with an occasional watering. In October, plant 1 was given two applications of an ammonium sulfate solution. Photographed December 10, 1926. This photograph illustrates the fact that the condition shown in plant 2, which is often attributed to drouth injury, is the result of nitrogen starvation.

B. The effect of nitrogen supply on the death of tobacco leaves. The two plants of Maryland Mammoth tobacco were set April 13, 1926. Plant 1 received no treatment and frenched on July 2, while 2 received a total of 960 cc. of a KNO_3 solution containing 25 g. per liter and 100 cc. of $(NH_4)_2SO_4$ solution, 25 g. per liter, between the date of setting and July 27, 1926, and did not french. Photographed November 2, 1926. Due to its greater leaf area and small soil volume plant 2 wilted practically every day thruout the summer and fall. The smaller plant seldom wilted.

THE RELATION OF THE NUMBER OF PLANTS PER POT TO SIZE AND TIME OF FRENCHING

The figures given in table 1 suggest a definite relation between number of plants per pot and size of the plants when frenching occurs. If frenching depends upon a ratio between plant size and available nitrogen, several plants grown in a pot, and one in the same amount of soil should french when a certain volume of growth has taken place. To determine the effect of growing various numbers of plants in a given quantity of soil, under otherwise similar conditions, a test was started April 22, 1926, in which the same weight of soil collected the previous day from the woods was put in to each of fifteen one-half gallon jars. The soil was previously sieved and thoroly mixed. One, two, three, four, and five small Turkish plants were set per pot, the experiment being run in triplicate. The plants developt rapidly but the development of all plants in a given pot was not always uniform, as certain plants started quicker than others. Where this occurred, however, the larger plants seemed to make up for the slower growth of the smaller, as will be seen by the average size of the plants. Frenching commenced May 24 (32 days) in the pots containing 4 and 5 plants; in the pots with three plants it commenced three days later and in those with one and two plants frenching developed after 36 days. The larger number of plants evidently occupied the soil volume

TABLE 2.—The Relation Between Number of Plants Per Pot and Time of Frenching. Plants Set April 22, 1926, in Triplicate.

No. of Plants Per Pot	Date of Frenching	Days Required	Ave. Height of Plants. Inches	Ave. No. of Leaves Per Plant	Ave. Total Weight of Plants Per Pot. Gms.		Ave. Weight Per Plant Gms.	
						Dry	Green	Dry
1	May 28 to 31	36 to 39	13.3	15	37.8	3.2	37.8	3.2
2	May 28 to 31	36 to 39	7.6	8.2	35.8	3.1	17.9	1.5
3	May 27 to 28	35 to 36	5.9	6.8	38.9	3.6	12.5	1.2
4	May 24 to 27	32 to 35	5.7	6.4	42.0	4.1	10.5	1.0
5	May 24 to 28	32 to 36	4.9	5.8	41.5	3.9	8.3	.8

more quickly and depleted it of available nitrogen more rapidly than the smaller number of plants, altho the difference was not great. (Figure 10B.)

The plants were cut off at the surface of the ground May 31, and the green weights and later the dry weights determined. The average height, number of leaves, green weight and dry weight per plant at the time of frenching decreased as the number of plants per pot increased (table 2). The average total green and dry weights per pot, tho somewhat less in the pots with fewer plants than in those with a larger number, approach equality rather nearly, showing that approximately the same growth per pot was made before frenching occurred. On May 19, five days before frenching occurred in any plants, nitrogen starvation was evident in the lower leaves of the plants in the pots containing three, four, and five plants while it was not yet evident in the plants growing singly or in pairs when they were harvested.

SOURCES OF NITROGEN USED IN THE CONTROL OF FRENCHING

In the course of work with Turkish tobacco plants, it has become a routine practice to apply some extraneous source of nitrogen for the plants when they begin to show signs of nitrogen deficiency or develop frenching, in order to keep them in a normal growing condition. Sodium and potassium nitrates and ammonium sulfate have been used with such marked success in the control of frenching after it has developt and also in many cases to prevent frenching that it may be said that the addition of one of these nitrogen compounds in sufficient quantities to a frenched tobacco plant under the conditions in which our work has been conducted will bring about recovery in an otherwise healthy plant in the course of a few days (Figs. 4 and 7). The results obtained suggest that any of the common sources of nitrogen used in fertilizers should be efficient in bringing about recovery. In the following tests a series of plants were used in which three plants were set in virgin soil in one-half gallon jars on February 6, 1926. When the test was begun on April 15, all the plants in the series used for this study had frenched. Ap-

proximately the same amount of nitrogen (.16 gram) was added in each treatment described. (Roughly 450 parts of NO_3 per million of ovendry soil.)

Floranid (commercial). This is a commercial synthetic urea and contains 46 percent nitrogen. Forty cc. of floranid solution containing 9 g. per liter were added to one jar of three frenched plants. In six days the plants were a darker green color; in eleven days the only signs of frenching were on three old leaves of the tallest plant. In 14 days the new growth in two plants was again frenched and the third frenched in 25 days from the beginning of the test. A second application of 100 cc. of the same solution was made on this date. In nine days recovery was complete in all three plants, and 26 days after this date the plants were still a dark green color.

Ammonium carbonate. Forty cc. of a solution of ammonium carbonate (C. P.) 12 grams per liter, were added to a jar of three frenched plants. In six days the plants were showing signs of recovery altho still slightly affected, while in eight days the new growth was healthy but faint signs of chlorosis were still visible on a couple of older leaves. Three days later the largest plant was again frenched, and in the next two days the other two plants frenched. On May 8 all three plants were severely frenched and 100 cc. of the same solution was added. Ten days later recovery was complete. Six days later the plants were all dark green and a month later were still healthy.

Urine (human). One hundred cc. of human urine (nitrogen content not determined) was added to three frenched plants. In two days the plants were badly wilted and remained so for several days. On April 26 the growing points, altho still chlorotic, seemed to be recovering. Two days later they were a very dark green. The new leaves were close together forming a rosette which on May 3 was beginning to be lop-sided, the shorter leaves on each plant being toward the center of the pot. Nearly all the original leaves had died by this time. By May 25 the plants were again making a normal dark green growth.

As 100 cc. of urine had caused injury in the above test, another test was started May 10, 1926, using a pot of three plants

which had been started February 6, and which had been frenched for 9 days when the following applications were made. Ten cc. of urine were added on May 10 and 12, 20 cc. on the 17th and 21st, and 10 cc. again on the 25th. The plants were becoming dark green at the growing point on the seventh day, were nearly completely recovered on the ninth day, and on the eleventh day recovery was complete. On June 16 the plants were dark green and had made excellent growth.

Leunasalpeter (Ammonium sulfate-nitrate, commercial). Forty cc. of a solution of leunasalpeter containing 17.8 g. per liter was added to a pot of three frenched plants. This chemical contains 26 percent nitrogen, one-fourth of which is in the form of nitrate and three-fourths ammonia. In eight days from the time of application recovery was almost complete, and in ten days was complete. On May 10 the three plants were again frenched, and received 10 cc. of the solution. In 7 days recovery was complete and a month later the plants were still dark green with large leaves and were in full bloom.

Potash ammonium nitrate (commercial). On April 12, 1926, 40 cc. of a solution of potash ammonium nitrate, containing 26.6 grams per liter was added to a jar of two frenched plants. The chemical contains 15.5 per cent nitrogen one-half of which is nitrate and the other half ammonium nitrogen. In 8 days recovery was complete. In 17 days the plants were again frenched and two days later received 100 cc. of the solution. In seven days recovery was complete and a month later the plants were still healthy and vigorous.

Sodium Nitrate (commercial nitrate of soda). Forty cc. of a nitrate of soda (15 per cent) solution containing 27.5 grams per liter were added to a pot of two frenched plants April 21. In nine days the plants appeared to be recovering but were still distinctly frenched. Eight days later they were still frenched, when 100 cc. of the same solution was added. In 8 days the plants were completely recovered and making excellent growth. A month later the leaves were large and dark green, appearing entirely healthy.

Ammonium sulfate (commercial). Forty cc. of a commercial amonium sulfate solution containing 20.07 grams per liter was added to a pot of two frenched plants April 21, 1926. In five days plants appeared to be recovering and three days later were completely recovered.

Checks. No treatment. On May 1 these plants were becoming worse. By May 9 each was developing a rosette of small leaves which had assumed normal color. The lower leaves were quite yellow indicating nitrogen deficiency. On May 21 the plants again showed frenching symptoms in the growing point. They were making poor growth and appeared unhealthy. The interchange of frenching symptoms with those of nitrogen deficiency as it is generally understood, is of interest in showing the close relationship between these two conditions.

Another series of tests were run using other sources of nitrogen. The plants used were set three per pot February 6, 1926. Frenching had occurred in practically all of this group of plants by April 15, 1926.

Complete fertilizer. Three and eight-tenths grams of a complete commercial fertilizer analyzing N, 4.16 percent; P_2O_5, 11.45 percent; and K_2O, 5.62 percent, was added to one pot containing two frenched plants on April 27, 1926. In six days the plants showed marked signs of recovery and were the darkest green of this and the preceding series. The next day recovery was complete. At the end of a month they were still healthy.

Dried blood. One gram of dried blood containing 14 per cent of nitrogen was added to a pot containing three frenched plants, on April 27. Twenty-one days later the plants showed no signs of recovery and two grams more were added. Thirteen days later the plants were showing marked signs of recovery and shortly after recovered completely, taking on a dark green color. The recovery was slow, with this material, as the nitrogen is not as readily available as in some of the other materials used

Calcium cyanamid (commercial). Calcium cyanamid was used on one pot of frenched plants. Eleven and eight-tenths grams of the commercial product were added to a liter of water, and 40 cc. of this applied on April 27, 1926. Eleven days later

strap leaves had developt on two of the plants and the third had developt mosaic. The mosaic plant was removed the following day by cutting off at the ground level. On May 13, the two remaining plants were still frenched and strap-leafed. One of the plants was removed on this date for other purposes as it did not seem that the material added would bring about recovery. On this date (May 18) double the original application of calcium cyanamid was added. In ten days the remaining plant had recovered and did not show signs of nitrogen deficiency during the next three weeks. There was a question whether the chemical or the removal of the other two plants brought about recovery in this case but a later test showed that altho calcium cyanamid acted very slowly it would bring about recovery of frenched plants eventually.

Raw bone meal. Six and five-tenths grams of raw bone meal containing 2.47 percent nitrogen was added to one pot containing three frenched plants on May 27. On June 8 the plants seemed to be recovering slowly and by the 11th, altho the plants were not as green as some of those receiving a more available form of nitrogen, the frenching symptoms were very faint. Two days later they had disappeared. Two days later, on the 15th, the plants were again frenched slightly. On the 18th, 13 grams of bone meal were added. On July 10 the plants were fully recovered. This is evidently a very slowly available source of nitrogen as compared with some of the readily soluble materials but it appears to bring about recovery from frenching if given sufficient time and if supplied in sufficient quantities.

Fresh stable manure. Twenty-eight grams of fresh horse manure (nitrogen not determined) was added to one pot of frenched plants on April 27, 1926. On the twenty-first day there was no sign of recovery and 56 grams of the same manure was added. June 10 the new growth was not frenched but the older leaves still showed signs of the disease, and nitrogen deficiency was evident in all the plants. On June 16 the new growth appeared to have recovered in two plants but the third which was blooming was still frenched.

Superphosphate. Two and one-tenth grams of superphosphate were added to one pot containing two frenched plants, as it is sometimes supposed to have a beneficial effect on nitrification. It had had no effect by May 18, and 4.2 grams more were added. On June 16 the plants were still badly frenched and were discarded.

Dried ground tobacco stalks. Five and seven-tenths grams of dried ground tobacco stalks containing 2.7 percent nitrogen were added to one pot containing three frenched plants. The application was made April 27 but by the 18th of the following month no sign of recovery was apparent. Eleven and four-tenths grams more were added on this date. On June 16 the plants were free from frenching and appeared healthy. It is probable that heavier applications of a material of this kind at the time of the initial application would have had more beneficial results than the small application given.

Ferrous ammonium sulfate. One hundred cc. of a solution containing 23 grams of ferrous ammonium sulfate per liter were added to one pot of three frenched plants on April 27. The sulfate contained 7.1 percent of nitrogen. In six days the plants were showing signs of recovery, and had taken on a darker green than any other plants in the series except those receiving a complete fertilizer. On May 10 recovery was complete in all leaves. Fifteen days later the plants were again frenching and received 100 cc. of the original solution. Four days later they showed signs of recovery but by June 16 when they were discarded they had not completely recovered. In subsequent tests using this source of nitrogen erratic results were obtained with the second application, some plants recovering completely while others grew rapidly but remained frenched.

Checks. Two pots, one containing one plant and the other three, were kept as checks on the above. The first was producing strap-leaves when discarded on June 16, having been severely frenched thruout the test. The other contained three badly frenched plants on May 28, at which time two of them were cut off to see if that might bring about recovery of the third. This was done as a check on the effects of calcium cyanamid, where

recoverey did not occur until after two plants were cut off. Altho the check plant was kept until July 27, it showed no signs of recovery.

It is evident from the above tests that a great variety of nitrogenous materials may be used as sources of nitrogen in bringing about recovery of frenched plants. It is also of interest that, with the comparatively large application of nitrogen given (450 ppm.) the plants remained healthy but a few days when they again frenched. A larger application then brought about permanent recovery in nearly every case. It is difficult to explain these results on any other basis than that nitrogen is the limiting factor, and that the starved plants took up the available supply of the first application rapidly, supplying starved tissues thruout the plant, thus increasing photosynthesis and growth and consequently increasing the requirement of the plant for nitrogen with the result that it again frenched.

COMPARISON OF AMMONIUM SULFATE AND SODIUM NITRATE AS SOURCES OF NITROGEN FOR FRENCHED PLANTS

In the tests on sources of nitrogen used in control of frenching, the results suggested that a given amount of nitrogen in the form of ammonium sulfate was more beneficial to a frenched plant than the same amount of nitrogen carried in the form of sodium nitrate. Two other tests were conducted to obtain further information on this point. In one of these ammonium sulfate seemed to be more beneficial than sodium nitrate while in the other there was no advantage either way. As conditions were not entirely comparable in the first of these tests, a third was begun using both C. P. (analyzed) and commercial ammonium sulfate and sodium nitrate. This test indicated no difference in the value of the nitrogen from the two sources in the control of frenching. The plants used were set one per pot in one-half gallon jars on June 5, 1926. The plants commenced to french July 3. The frenching was a mild type in each case, the leaf shape being normal, but chlorosis was clearly evident between the larger veins. On July 19 each plant received .16 gram of nitrogen from the respective sources. Recovery was remarkably uniform in the whole series. With two exceptions all

the plants were completely recovered in the growing point in four days and the two recovered on the fifth day. In several plants there was still a faint pattern in some of the older leaves at this time, but it could only be seen on close observation. It had completely disappeared in all plants in another three days. In this test six frenched plants were kept as checks. Thruout the test they showed marked signs of nitrogen deficiency, altho the frenching pattern was not continuously present in the growing point. On August 8 all but one of the check plants showed marked frenching symptoms in the growing point and were growing very slowly. In contrast, the new leaves which developed on the treated plants were of a normal size and the upper ten older leaves at least took on a dark green color. On August 8 the treated plants were all in full bloom. The results seem to indicate that ammonium sulfate and sodium nitrate are equally efficient sources of nitrogen for tobacco. In another test in which severely frenched plants growing in tumblers were treated with .04 g. of nitrogen using ammonium sulfate and sodium nitrate as sources, the ammonium sulfate stimulated the plants to a more rapid, dark green growth, with quicker recovery, than sodium nitrate.

ATTEMPTED CONTROL OF FRENCHING IN LARGE TOBACCO PLANTS

Altho it appears quite certain that frenching is due to an improper balance between the rate of carbohydrate metabolism and the intake of nitrogen from the soil, there is still a question whether the addition of nitrogen in the form of any of the commercial nitrogen carriers will bring about control in the field if applied in amounts which are within economic limits. It is possible that frenching cannot be economically controlled in this way, but must be controlled thru bringing about conditions in the soil which will speed up nitrification to a point where it will furnish sufficient nitrate for a balanced nutrient solution.

In the work with Turkish tobacco plants the amount of soil has been small and the plants naturally have not grown to the size they would in equally fertile soil in the field. Nitrogen deficiency can therefore be met by the addition of a compara-

tively small amount of nitrogen in a soluble form. The following experiment indicates that it may be difficult and, from the practical standpoint, possibly out of the question, to supply nitrate to rapidly growing frenched plants in the field as fast as it is required. Two F_1 hybrids of *Nicotiana rustica* X Burley were being grown in the greenhouse the winter of 1925-6 in an attempt to obtain F_2 seed. These two plants were set in two-gallon jars of virgin soil April 1, 1926, after having grown in one-half gallon jars since February 15. On May 10, both plants were growing very rapidly when each was given 50 cc. of an ammonium sulfate solution containing 20 grams per liter. The larger plants showed signs of frenching five days later. The leaves in the growing point were chlorotic and some of the leaves were cupped downward somewhat as in Fig. 9. These plants showed no signs of nitrogen deficiency in the lower leaves as the Turkish plants usually do. On May 19, the second plant frenched. The plants will be designated Nos. 1 and 2, respectively. It was decided to try to control frenching in No. 1 and leave No. 2 as a check. No. 1 received nitrogen as follows: May 21, 100 cc. of a KNO_3 solution containing 25 grams per liter; May 25, 26, 27, and 29, 50 cc. each day, and May 31, June 3, 4 and 5, 100 cc. each day. On this date plant No. 1 was growing rapidly, eight-inch shoots having developed from the axils of nearly all the leaves and the plant had formed a flowering stalk. The lower leaves were very dark green but the upper leaves still had a distinct frenched pattern. The lateral shoots of plant No. 2 had just started at this time, the lower leaves were yellow and the plant as a whole was showing nitrogen starvation. No. 1 received another application of 100 cc. on June 6, 200 on the 18th and 100 cc. on the 22nd. Frenching symptoms had disappeared on June 18. Plant No. 2 was still frenched July 2, when in full flower. Plant No. 1 had received a total of 27.5 grams of potassium nitrate from the time frenching commenced until the plant again had assumed a healthy color thruout. This was a large plant attaining a height of approximately seven feet. The leaves were not so large as would be expected to develop in the field but the plant compared more favorably

Fig. 9.—Frenching of *Nicotiana repanda*. The leaves are chlorotic and cupped downward due to failure of the blade tissue to expand properly. This plant was grown in a pot of virgin soil with many others. Nearly all the plants were removed before photographing.

with field plants than any which had previously frenched in the progress of these studies. On an acre basis the nitrate added in this case was at the rate of 424 pounds of KNO_3, based on 7,000 Burley plants to the acre. There is some question as to whether, with the cost of material and labor, the application would be worth while, and of course it is not certain from these tests that frenching would be controlled in the field by the application of soluble nitrate.

This experiment, and others in which too small amounts of nitrate have been added to bring about rapid recovery, should be given careful consideration in connection with failure to control pecan and apple rosette by the addition of nitrogen in the form of soluble salts. It seems evident that the plant must first be supplied with sufficient nitrogen to care for partially starved tissue and then must have a constant available supply of nitrogen in order that it may *remain* healthy. It also seems evident that the addition of nitrogen at only one time might eventually do more harm than good by developing a more active leaf area, thus bringing about a carbohydrate reserve which, in periods of abundant moisture, might result in a frenched growth whereas a limited chlorotic leaf area might manufacture carbohydrates only as fast as nitrogen is available to use them in growth, thus resulting in an apparently healthy but slow growing plant.

AMOUNT OF NITROGEN NECESSARY TO PREVENT THE OCCURRENCE OF FRENCHING IN TURKISH TOBACCO

The tests of various materials as sources of nitrogen indicated clearly that it is not enough to add nitrogen sufficient to bring about recovery, but the plant must have a constant supply of it if it is to remain healthy. In order to determine approximately the amount of nitrate which must be added to the virgin soil to prevent plants from frenching, eight pots, each containing three plants of tobacco, were selected. The plants were uniform in size and appearance and were all showing signs of nitrogen deficiency in the lower leaves but had not yet frenched. The test was begun on March 24, 1926, on which date nitrate was added in the form of KNO_3 as follows: Pot 460 none, 461, approximately 6.5 parts of NO_3 per million of oven-dry soil; 462, 13 ppm., 463, 26 ppm., 464 52 ppm., 465, 104 ppm., and 466, 208 ppm. Similar treatments were given April 8 and 22. In from 23 to 35 days, from the time of the first application, frenching had occurred in all the plants in pots 460 to 464, inclusive, or in those receiving 52 ppm. of NO_3 or less, while no frenching had developed in 43 days in the pots receiving 104 and 208 ppm., the plants having taken on a dark green color. At this time (May 6) none of the plants which had frenched showed signs of

recovery, in spite of the three applications of nitrate. The plants were cut down to about two inches in order to allow new shoots to develop and to determine the effect of reversing the treatments on the development of frenching. At the time of cutting back the treatments were reversed, the check plants were given no treatment; 461 received 416 ppm. (previously 6.5 ppm.) of NO_3 in the form of KNO_3; 462 received 208 ppm.; 463, 104 ppm., 464, 52 ppm. as in the previous tests 465, 26 ppm.; 466, 13 ppm., and 466A (a pot of the same size plants which was given 416 ppm. on April 22, and cut off on May 6) was given 6.5 ppm. of NO_3. It will be recalled that frenching was present in all the plants, except those in the last three pots mentioned, when the plants were cut off.

The results of the second treatment were as follows: The check plants receiving no nitrate developed shoots which frenched as soon as they developed, and remained frenched with the exception of two days following a dull period of weather when a considerable number of plants in the house either recovered or showed marked signs of recovery. The plants receiving 416 and 208 ppm. (previously frenched) developeed vigorous shoots of a dark green color which remained healthy. Plants in pot 463 (104 ppm., previously frenched) which had previously received 26 ppm. developed frenched shoots with strap leaves from the beginning. The leaves soon turned dark green and developed to about the same length as in the pots receiving more nitrate but narrow leaves continued to be produced for about 43 days, at which time they took on a more normal shape and twelve days later the new leaves in the growing point were of normal shape. Two days later there were slight signs of chlorosis in the growing point, but in ten days the leaves were again green showing no signs of frenching. Plants in pot 464 which thruout had received 52 ppm. showed signs of the disease 13 days after being cut off and remained frenched until July 28 when the growing points recovered as the check plants had done, altho the plants still appeared starved. Plants receiving 26 and 13 ppm. (previously healthy) frenched soon after growth started and remained frenched until about July 15 when the

new growth in all the plants was a normal color but symptoms of frenching were still evident in the older leaves. The plant in pot 466A which had received one application of 416 ppm. before cutting and 5 ppm. since did not french altho it later developed marked symptoms of nitrogen starvation in the lower leaves.

The growth of the plants in the above series was markedly influenced by the amount of nitrate added. On July 16, 1926, the check plants averaged 5.5 inches, while the plants in the pots receiving the three highest doses of nitrate averaged 36.6, 29.5, and 20.6 inches in height, respectively. In the next four pots the plants averaged 14.3, 16, 15.5, and 12.2 inches, respectively, the latter receiving the smallest application of nitrate. That differences in growth and frenching were not due to differences in plants or soil but were the result of the nitrate added was indicated by the fact that by reversing the order of application of nitrate the rates of growth were reversed to quite a marked degree and frenching was developed in plants which had previously been healthy and cured in plants which had previously been affected. The uniformity of the plants and soil used in this experiment was further indicated by cutting the plants back again to stubs and giving a uniform application of 208 ppm. of NO_3 to each pot except the check which received none. Its suckers developed badly frenched strap leaves which were in the same condition several weeks later. Frenched suckers developed in pots 463, 464, and 465 (102 to 26 ppm., respectively, in previous test) but by the 25th of the month they had all completely recovered and the plants in all but the check pots were uniform in size and making a very uniform healthy growth.

The results of this test indicate that plants growing in this particular soil and under the conditions of this test will not french, after nitrogen starvation has become evident, if they receive applications of nitrate equal to 104 ppm. of over-dry soil every two weeks, but will french if they receive half of this application.

Fig. 10.—A. The effect of nitrate on the growth of Turkish tobacco plants in sand. From left to right the plants received 0 10, 40, 80, and 160 parts per million of NO_3 in the form of KNO_3. Photographed April 19, 1926.

B. Showing the relation between number of plants per pot, size, and time of frenching of Turkish tobacco plants in virgin soil. 1, 2, 3, 4, and 5 plants per pot were set in pots 525 to 535, respectively.

PRODUCTION AND CONTROL OF FRENCHING IN SAND CULTURES

On March 3, 1926, a series of plants was started in sand cultures in an attempt to produce frenching. Various amounts of nitrate were used together with a uniform fertilizer treatment consisting of 2.5 grams of acid phosphate, 3 grams of ground limestone and 20 cc. of a nutrient solution[3] to one-half gallon jar of river sand. The series was run in duplicate. The pairs of pots received 0, 5, 10, 20, 40, 80, and 160 ppm. of NO_3

[3] Containing 25 grams KH_2PO_4; 25 grams $MgSO_4,7H_2O$; 0.5 grams $MnSO_4,4H_2O$; 0.5 grams $FePO_4$.

to oven-dried sand, in the form of KNO_3 in aqueous solution. The plants were watered with distilled water thruout. The relative rates of growth of the plants receiving different amounts of nitrate is shown in figure 10A. Growth is proportional to the amount of nitrate added. The first frenching appeared in forty-one days. By the sixty-ninth day all but two plants had frenched and these remained free from symptoms thruout the experiment altho they showed nitrogen starvation. There appeared to be no relation between the amount of nitrate added and the time of appearance of the symptoms of the disease in sand cultures; thus in the slower growing plants resulting from smaller applications of nitrogen the deficiency of nitrogen with reference to carbohydrate production may not appear any earlier than in rapidly growing plants resulting from larger applications of nitrogen.

After sixty-six days (May 8) nitrate was again added to one of each series of pots in the same proportion as the original application and again at about ten day intervals until five applications had been made. This was done in order to determine if possible the amount of nitrate necessary to bring about recovery in sand. The results are recorded in table 3. In each case where nitrate was added growth was increased. Forty parts per million of nitrate appeared to lessen the degree of frenching but did not control it. Eighty and one-hundred sixty parts brought about complete recovery, the leaves being dark green and free from any symptoms of the disease. From these results and from the previous ones with soil cultures it seems that nitrate must be present in the soil or sand in amounts equal to more than fifty parts per million of air-dry soil or sand in order to maintain a proper balance between nitrogen content and carbohydrate metabolism in Turkish tobacco plants grown under these conditions. Morris (13) found the nitrate content in soils where apple trees were either apparently healthy or rosetted to be about 72 ppm. and concluded from this that lack of nitrate was not the cause of rosette of apples. His determinations in the orchard and the results of the above tests are in quite close agreement for the requirements of the two crops.

TABLE 3.—Showing the Effect of the Application of Nitrate in Varying Quantities to Frenched Plants in Sand Cultures.

Pot No.	P. P. M. NO_3 Added 5 Times at 10-Day Intervals to Frenched Plants, Between May 8 and June 17, 1926	Condition of Plants July 13, 1926
446	0	Frenched, yellow, 6 in. tall.
449	5	Frenched, yellow, 10½ in. tall.
450	10	Frenched (strap leafed), yellow, except upper leaves, 15½ in. tall.
452	20	Frenched, lower (⅓) leaves yellow, 20 in. tall.
454	40	Slightly frenched, 34 in. tall.
456	80	Healthy dark green, few leaves dead.
459	160	Dark green, growing rapidly, 40 in. tall.

THE EFFECT OF PARTIAL STERILIZATION OF SOIL ON FRENCHING

The results of the soil packing experiment in which plants grown in tumblers frenched soon after growth commenced, led to a further study of plants grown in small volumes of soil, with the object of determining the effect of heating soil to a temperature of 65 to 75°C.[4] This had been (20) found sufficient to destroy root-rot producing organisms. A uniform lot of sieved virgin soil was measured into each of 70 tumblers and one-half of these were partially sterilized on October 29, 1926. A plant of Turkish tobacco was then set in each tumbler from a bench of unsterilized virgin soil. One-half of the plants in each lot were then watered with distilled water and the other half with tap water, making four lots in all. The results obtained after growth commenced were very striking. The plants in partially sterilized soil gradually took on a dark green color, while those in untreated soil became somewhat chlorotic and, when about three inches high, frenched. In 38 days the height of the plants in the four series was determined with the following results:

[4] The soil was raised to this temperature in an autoclave and when the center of the soil volume reached the desired temperature, it was held for 15 minutes, removed from the autoclave and allowed to cool. The heat treatment, of course, was much longer than 15 minutes.

TABLE 4.—Effect of Partial Sterilization of Virgin Soil on Growth and Frenching of Turkish Tobacco.

Average Height of Plants in

Untreated Soil Watered With		Partially Sterilized Soil Watered With	
Distilled Water	Tap Water	Distilled Water	Tap Water
16 frenched plants, 3.1 ins. 2 unfrenched plants, 3.0 ins.	4 frenched plants, 3.8 ins. 9 unfrenched plants, 4 ins.	18 healthy plants, 6.3 ins.	17 healthy plants, 6.6 ins.
Average 3.4 ins.		Average 6.4 ins.	

The plants in the treated soil were about twice the height of those in untreated soil (Fig. 11A), the majority of the latter being frenched and all of them showing the usual signs of nitrogen starvation. In 50 days the plants in untreated soil had made but slightly more growth while those in partially sterile soil were between 10 and 13 inches high. The plants within each lot were quite uniform in size, but those in untreated soil watered with tap water varied slightly more in size, and did not show the uniformity in time of frenching shown by the plants watered with distilled water. It will be noted that in both untreated and treated soil watered with tap water the plants were slightly larger than those watered with distilled water. Untreated soil from this experiment, in which frenched plants had developed, when heated, resulted in a marked increase in growth of the plants set in it over those previously grown but the plants did not attain the size of plants grown in fresh soil heated. One of the plants in the used heated soil frenched after showing nitrogen starvation for some time.

An examination was made of the root systems of two plants, one grown in treated soil and the other in untreated soil. Both systems appeared white and healthy. In the course of these studies many other root systems of plants grown in the untreated soil have been examined, but no signs of root injury have been found, apparently eliminating the possibility of soil pathogenic organisms being a factor in these experiments.

Fig. 11.—The effect of heat treatment and nitrogen on the growth of Turkish tobacco and on frenching. A. The plants on the left were grown in soil that had been raised to 65°C. They appear healthy and green. The plants on the right were grown in the same virgin soil untreated. They are frenched in the growing point and all leaves are light green. Plants set October 29, 1926 photographed December 10, 1926.

B. 1 and 2 in soil that had been heated to 65°C. Plant 2 received .04 gms. nitrogen as ammonium sulfate, when about 12 inches high. It shows slight signs of nitrogen starvation in the lower leaves. Nothing was added to No. 1. The other plants are in unheated virgin soil. No. 6 received no addition and is a typical frenched plant. The others received .04 gms. of N each, No. 3 as ammonium sulfate, No. 4 as ferrous ammonium sulfate and No. 5 as sodium nitrate, added December 10, 1926. Photographed January 3, 1927.

Total nitrogen was determined in 9 of the frenched plants grown in untreated soil and in 12 of the healthy plants grown in heated soil. The former contained 1.79 percent and the latter 2.02 percent nitrogen, in the air-dried material.[5]

Nitrogen was added to six of the tumblers of frenched plants watered with distilled water, .04 g. of nitrogen in the form of ammonium sulfate, sodium nitrate and ferrous ammonium sulfate being added, respectively, in duplicate. The plants soon showed signs of recovery and after 10 days the growing points of all of the treated plants had practically recovered. The plants were still a light green color but darker than the untreated plants. Growth was stimulated by the applications so that three weeks later the plants were rapidly approaching the size of those in treated soil (Fig. 11B).

The results obtained in tumblers have been confirmed, using half-gallon jars of the same soil untreated and heated to 65°C. Two plants of Turkish tobacco were set in each jar. The growth in the two series was comparable for a time, but it became more rapid in the treated soil, the plants becoming top-heavy and falling over as compared with erect, more slender plants in untreated soil. The plants in untreated soil frenched at a height of 12.3 inches and made little further growth, while the plants in treated soil grew to more than twice that height and did not french.

A second crop of plants grown in the heated soil reheated, to which was added 10 percent of virgin soil, frenched soon after a lot of plants grown in untreated virgin soil. A second crop of plants grown in heated soil to which no virgin soil was added made poorer growth than plants grown in unheated virgin soil, showed nitrogen deficiency, and appeared in general like the two previous lots except that the leaves of the growing point did not become frenched.

It is generally recognized that the chief effect of partial sterilization of soil on plants (other than the destruction of pathogenic organisms) is in the transformation of nitrogen compounds into forms in which they are available for plants.

[5] The determinations were made by Dr. J. S. McHargue to whom we are indebted.

The results obtained by partial soil sterilization in these experiments are comparable to results obtained by the addition of available nitrogen compound to virgin soil, again confirming the nitrogen theory of frenching.

RECOVERY OF FRENCHING BY THE INTRODUCTION OF NITROGEN COMPOUNDS INTO THE UPPER PORTION OF THE PLANT

When nitrogen compounds are introduced into the soil and bring about recovery from frenching, the question arises as to whether recovery is due to the direct action of nitrogen compounds on the plant or whether the effect is a secondary one resulting from the action of the nitrogen compound on the soil, liberating some other necessary material for plant growth. Therefore attempts were made to introduce nitrogen compounds directly into the upper part of the plant rather than thru the soil. A preliminary trial resulted largely in failure. The stem of the plant was cut into and split upward for about 1½ inches and the cut end inserted into a beaker containing a weak solution of nitrate. Success was obtained, however, when frenched plants about 14 inches high growing in virgin soil were bent over and tied down until the growing point was again directed upward. The bend behind the growing point was then placed in a tumbler of washed sand where it rooted. It was then a simple matter to feed nitrogen to the upper portion of one plant of a pair in a pot without supplying it to the other, while both received other nutrients from the soil.

Recovery of the plant to which nitrogen was supplied in this way was as prompt as when it was supplied thru the soil, while the check plant growing in the same soil, but receiving distilled water thru the new roots, remained frenched and grew much more slowly. The same results were obtained when the upper part of the plant was rooted in a tumbler of water and nitrogen compounds added to it. An interesting point developed in these tests with regard to the distribution of nitrogen in the plant. Soon after the plants were bent over, buds started into growth from the base of the plant. In some cases these were allowed to grow. In both the treated and untreated plants the shoots which developed were frenched whereas the terminal

growth of the treated plant was dark green and healthy. The nitrogen taken up by the upper portion of the plant apparently was not available to growing parts lower down on the stem. The results of these tests seem to prove that inorganic nitrogen compounds in themselves are able to bring about recovery of frenched tissue when introduced independently of other nutrients.

THE EFFECT OF LIME ON FRENCHING

Frenching of citrus trees, apparently induced by lime, as reported by Floyd (5) has certain characteristics which closely resemble frenching of tobacco. The terminal growth is chlorotic as in tobacco frenching and, later, defoliation occurs similar to that of frenched tobacco grown in pots. The soils on which this condition developed, following applications of lime, were low in organic matter and inclined to be dry. The first result of the lime was to stimulate growth of grapefruit trees on sour orange roots. This was during the second year's growth. The third year frenching occurred. It affected not only the citrus trees but likewise the cover crop of beggarweed (legume). A light application of stable manure resulted in restoring the leguminous cover crop to a more normal condition while goat manure did not have this effect. The assumption was that increased growth of the legume following the application of stable manure resulted from the addition of bacteria to the soil. In other words, it seems that both the leguminous cover crop and the trees were suffering from nitrogen starvation, and that this condition was in part remedied by the addition of stable manure carrying with it nitrogen and organic matter and thus furnishing energy for soil microorganisms, while it was not remedied by the addition of dry goat manure which was probably low in nitrogen and organic matter and formed a poor medium for microbial activity. As microbial activities play a large part in making nitrogen available to plants the effect of stable manure might well be explained as resulting from the addition to the soil of a medium favorable to their growth, rather than the addition of the bacteria themselves.

One case has been reported in the present paper in which lime, blown or washed from a road, has probably influenced frenching of tobacco. Another case where lime appeared to bring about frenching was observed on the tobacco rotation series at Campbellsville soil experiment field in 1927. Plots 8, 9, 11 and 12, series 500, were limed plots and Burley tobacco growing on them frenched badly during the early summer which was wet. Plots receiving no lime were entirely free from frenching, it stopping abruptly where lime left off. The same condition had been noticed in previous years but to a less marked degree.

A test was made to determine the influence of lime on frenching of Turkish tobacco using virgin soil. It was believed that, because of the influence of lime on breaking down organic matter in the soil, the plants to which lime was added would grow more rapidly and french later, if they frenched at all, than those in unlimed soil, in which available nitrogen has been shown to be deficient. CaO, at the rate of 10,000 parts per million, was thoroly mixed with virgin soil and placed in each of five one-half gallon jars. Five other jars of the same soil were not limed. Three plants of Turkish tobacco were set per jar the following day (Nov. 3, 1926). At first the plants in limed soil grew more slowly and were lighter green than those in unlimed soil. In five weeks, however, the limed plants were taller and in six weeks were much darker green than those in unlimed soil. Between the 47th and 52nd days the 15 plants in the unlimed soil frenched at an average height of 10.7 inches. Those in limed soil were then dark green with an average height of 12.3 inches. The difference in growth of the plants is shown in figure 6B photographed on the sixty-third day of the experiment.[6]

A second crop of plants was grown in the same soils both in tumblers and in glazed jars. In this crop both groups of plants grew slowly and both showed signs of nitrogen starvation early. The plants in the limed soil were somewhat smaller and slower growing than those in unlimed soil in contrast to the

[6] The pH of these soils as determined by the colorometric method using bromthymolblue was: virgin soil untreated 6.8; virgin soil limed 7.6. Using phenol red the limed soil was 7.4. The determinations were made by Dr. D. J. Healy.

first crop where the limed plants outgrew the unlimed. The addition of nitrogen to a pot of each series stimulated growth in both series and completely overcame signs of nitrogen starvation.

The results obtained here closely coincide with those obtained by Floyd on citrus; namely, marked stimulation of growth following the addition of lime, to be followed by signs of nitrogen starvation, with recovery again when a source of nitrogen was supplied. Altho the second crop of plants in the limed and unlimed series appeared nearly identical following the appearance of nitrogen starvation, those in the unlimed soil frenched, both in pots and tumblers, while those in the limed soil remained an even green color in the growing point. In this respect the results differed from the results obtained with citrus and raise a question as to the similarity of the two diseases. The difference may, however, be apparent rather than real. The increased growth of tobacco following the addition of CaO may have resulted from the effects of partial sterilization of the soil, as this chemical is one of those which brings about partial sterilization. In time the CaO changes to $CaCO_3$ and then the effect obtained should be the same as is expected from the addition of $CaCO_3$. The soil to which the lime was added was high in total N, as evidenced by the growth of plants in heated soil. The growth of the tobacco plants following the addition of CaO was not stimulated to the extent that it was by heating; therefore a considerable reserve of nitrogen was left in the soil for the second crop of plants. While these made slightly slower growth than those in unlimed soil, they were darker green in the growing point, suggesting a more constant supply of nitrogen to the growing plants than in unlimed soil. Two later crops in the same soil acted in the same way, the plants in limed soil remaining green while those in unlimed soil frenched. It seems probable, from these results, that crop after crop of plants in the limed soil would eventually result in a more complete depletion of total available nitrogen in this soil than in unlimed soil, where nitrogen is released to the plant more slowly. In a soil low in organic matter and consequently in total nitrogen, as in the

citrus soil, the expected result would be stimulation of growth due to increased liberation of nitrogen, with the development of a larger tree with increased nitrogen demand, and a much more rapid approach to a nitrogen deficiency in the soil, resulting eventually in more marked signs of nitrogen starvation and consequently frenching.

DISCUSSION

These studies lead us to believe that frenching of tobacco is a nitrogen deficiency disease resulting, in mild cases, in chlorotic vein islets, and in more severe cases, in partial or complete chlorosis of the leaf blade except in the larger veins, and in the most severe cases in complete chlorosis of the entire growing point of the plant. In the field, plants which have made a vigorous, dark green growth thruout most of the summer may suddenly french, suggesting that the mineral elements are not lacking but that some element which, in an available form, is transient in the soil, is the factor bringing about the disease.

Greenhouse studies with Turkish tobacco plants growing in one-half gallon glazed jars of virgin soil from a forest have shown that when the plants begin to show signs of nitrogen starvation they may be expected to french, but that if nitrogen in any of the available forms commonly used is added in sufficient quantities the plants will rapidly recover and if a reserve supply has been added may not again french. However, if only small applications are used, the plant may recover for a few days and again french. It is evident that the health of the plant (as far as frenching is concerned) depends upon a constant supply of nitrogen either from the soil or from an artificial source as long as the plant is growing actively.

The possibility that frenching may be due to a lack of some other element than nitrogen, which is carried in the nitrogen compounds as an impurity has, of course, been given consideration. The fact that any of the sources of nitrogen, whether commercial or C. P., organic or inorganic or that released in the soil by partial sterilization gave similar results argues strongly for the nitrogen deficiency theory. The further fact that nitrogen is the only element known to fluctuate very markedly in

its rate of availability in a given soil is another argument in its favor. It has been shown that seasonal conditions apparently have a marked effect on the length of time and the amount of growth required before a plant frenches in the greenhouse. The processes resulting in available nitrogen are biological, depending on temperature and moisture, at least in part, for their procedure. High temperatures and increased light in the greenhouse during late spring and summer seem to be correlated with rapid development of frenching, whereas the lower temperatures in the winter and decreased light appear to be correlated with slower development. The results obtained appear to be brought about either by the rate of biological activities going on in the soil, or by the slower growth of plants during the winter season as compared with spring, summer and fall, thus giving a longer time over which a given growth unit may obtain its nitrogen supply. That the reserve supply of nitrogen is not exhausted in soils in which frenching occurs is shown by the fact that on standing, in the absence of a plant, the soil will rapidly regain its ability to produce a healthy plant, and by the fact that heating the soil results in an abundance of available nitrogen.

The usual effect of a continuous deficiency of nitrogen on plant growth is to slow it up, the leaves becoming more or less chlorotic. In the field frenched plants are often dark green, except for the chlorotic growing point during periods of rapid growth. This suggests a rather high nitrogen content of the soil with the available supply of nitrogen temporarily reduced by certain conditions, as excessive soil moisture. In the greenhouse frenching is usually accompanied by signs of nitrogen deficiency in the lower leaves. Occasionally, in a lot of Turkish plants a few will not french as the others do but only show chlorosis of the lower leaves. In these instances it would seem that translocation of nitrogen were taking place from the lower leaves to the upper rapidly enough to maintain an equilibrium between growth and nitrogen supply. In plants which french, growth appears to proceed faster than the necessary nitrogen can be obtained either from the soil or by translocation.

The conditions which may bring about frenching, either in the greenhouse or in the field, we believe to be essentially as follows: The plant, in the presence of available plant foods including nitrogen, builds up leaf tissue capable of producing carbohydrates. Plants in the field during periods of dry weather when growth is checked by lack of water, probably store up supplies of carbohydrates far in excess of immediate needs. With the advent of a rainy period the soil is not likely to be well supplied with available nitrogen due to the previous drought or to leaching with the first heavy rain, but the plants will immediately start into rapid vegetative growth using up the stored carbohydrates; but in the absence of a sufficient available supply of nitrogen the resulting growth may be chlorotic. If the deficiency of nitrogen is prolonged the plants will definitely french. If conditions for nitrification are good the partially chlorotic tip growth will rapidly assume the normal color and appear healthy. As frenching occurs under a great variety of conditions the details of just what occurs under any given set of conditions will vary. However, we believe that the nitrogen deficiency theory of frenching will be found eventually to satisfactorily explain frenching of tobacco under the variety of conditions under which it occurs.

Frenching of tobacco, if due to a deficiency of available nitrogen, should be expected to represent a group of similar diseases in other crops and the conception of temporary nitrogen starvation in rapidly growing tissue may lead to a satisfactory explanation of other diseased conditions which, at first sight, appear not to be related to this problem. Corn, following a rainy period, will often make very rapid growth, the new leaves as they develop being quite chlorotic, remaining in that condition, in wet places, for several days. This we believe to be a manifestation of a temporary nitrogen deficiency in this plant and to be a condition identical with frenching in tobacco.[7] Pecan

[7] In the spring of 1927 specimens of cauliflower were received from the farm of Ed. Huber, Shively, Ky., which appeared to have a disease of the same nature as frenching of tobacco, as the leaves were narrow and chlorotic in the growing point. The disease followed a period of very wet weather. Following a report of this trouble in the Plant Disease Reporter (Vol. 11, No. 4, p. 40, 1927), Dr. Clayton called attention to the possibility of this trouble being identical with the disease of cauliflower which he had

and apple rosette are two diseases which have been considered to be due to abnormal soil conditions and have yielded to good soil management. A comparison of these diseases, and the conditions which bring about control, with tobacco frenching indicates that they are very similar in character (Table 5).

The results of the work on pecan rosette carried on for many years by the United States Department of Agriculture show clearly the relation between organic matter content of the soil, which determines nitrogen content, and freedom or recovery from pecan rosette. The same is indicated by the work of Clawson (3) and Whipple (21) and Morris (13) on apple rosette. There are certain facts, however, in the work of Morris which would at first seem to conflict with the theory that apple rosette is the same kind of disease as frenching of tobacco. Morris found in soil analyses that nitrate content averaged con-

---

described as whip-tail (E. E. Clayton, Investigations of Cauliflower Diseases of Long Island, N. Y. Agr. Expt. Sta. Bul. 506, 1924) and which he showed could be controlled by the addition of hydrated lime to the soil. The addition of lime was particularly effective where the soil was fertilized with potash or a complete fertilizer but appeared to be of little benefit in the unfertilized plot. These results might be explained on the nitrogen theory of the disease. Potash was evidently more of a limiting factor in untreated soil than nitrogen (see graph 1, p. 9 of Clayton's paper) as, with its addition on limed plots, the size of the heads was about doubled as compared with the size on limed but otherwise unfertilized plots. The potash could therefore be expected to stimulate the growth of plants where it was applied but if an abundant supply of available nitrogen were not present an abnormal growth of the frenching type might be expected. The addition of lime to the soil is known to stimulate nitrification due in part at least to a more favorable soil reaction for bacteria. Thus on the fertilized plots where abnormal growth had resulted from the addition of fertilizers, the liberation of an abundance of available nitrogen due to the addition of lime would bring about a balance in nutrients and a healthy growth would result. The addition of nitrogen in the fertilizers either in the form of dried blood or sodium nitrate appeared to have but slight effect on the incidence of the disease, but the amounts added were not stated and could readily have been insufficient to carry a rapidly growing crop thru to maturity in the absence of a readily available supply from the soil itself.

Another disease which appears to be of the same nature as frenching of tobacco is crazy-top of cotton (Cook, O. F. Acromania or "Crazy-top," a growth disorder of cotton. Jour. Agr. Rsch. 28, No. 8, 803-827, 1924). One of the early symptoms of the disease is a general shedding of buds and young bolls. This suggests nitrogen deficiency. The disease occurs in spots year after year, the spots increasing in size. A hard layer of soil is often present a short distance under the surface thus giving a limited feeding area to the plant as it develops. Where water was impounded and had time to penetrate the soil, the plants were healthy but where irrigation water ran off without penetrating deeply, the disease developed. The depth of the soil stratum wetted would determine the volume of soil in which the plant could feed and consequently its nitrogen supply in the later period of its growth. The disease was found to be more prevalent and to have more pronounced symptoms in soil cropped continuously to cotton than in fields where cotton followed alfalfa. King and Loomis (Factors influencing the severity of the Crazy-top disorder of cotton. U. S. D. A. Dept. Bul. 1484, 1-21, 1927) recognized the similarity between Crazy-top and pecan rosette as they state "A disease which shows parallels with Crazy-top in its relationship to cultural conditions and in some of its symptoms is pecan rosette."

TABLE 5.—A Comparison of Tobacco Frenching with Apple and Pecan Rosette.

Tobacco Frenching	Authority	Pecan Rosette	Authority	Apple Rosette	Authority
Nontransmissible by grafting, budding or juice inoculation.	Clinton and Wolf and Lehman	Same	Orton and Rand	Same	Judson, Morris
Chlorosis of growing point.		Same	Orton and Rand	Same	Morris
Strap leaves produced.		Same	Orton and Rand	Same	Morris
Rosette present under some conditions.		Same	Orton and Rand	Same	Morris
Associated with low available nitrogen content of soil.		Same	McMurran	Same	Whipple
Occurrence in a wide variety of soils.		Same	Orton and Rand	Same	Morris, Mix
Recovery with change of soil.	Clinton	Same	Orton and Rand	Recovery with change of soil conditions	Whipple, Clawson
Variation in severity with climatic changes.		Same	Orton and Rand	Same	Whipple, Mix
Control by addition of nitrogen compound.		Control by increasing humus and nitrogen content	McMurran	Control by plowing under or growing legumes	Whipple, Clawson

sistently higher from July 24 to September 15 in the vicinity of rosetted trees than in the vicinity of healthy trees in the same orchard, and concluded that the results "seem to indicate clearly that the lack of nitrate nitrogen in the soil is not a controlling factor in the development of apple rosette." Total nitrogen in the same areas was not determined. The fact that more nitrate nitrogen was found about the diseased plants than about the healthy ones in a soil known to be low in organic matter might readily be explained on the basis of the healthy tree having a much greater requirement for nitrogen during the period when the determinations were made than a tree which had a very much reduced leaf area, as the rosetted trees had, and in which the feeding root area may be expected to have been reduced due to a continued period of ill health. If the nitrate content were found to be consistently higher thruout the year in soils where trees were only showing the first signs of the disease and where the soil was well filled with active roots, as compared with healthy trees, it would be a serious objection to the nitrogen theory of apple rosette, but it is a well known fact that healthy plants keep the nitrate nitrogen content of a soil low by constant absorption during the growing period, whereas a soil in which no plants are growing or in which the soil is not completely occupied by vigorous roots the nitrate content has an opportunity to increase. Nitrogen content of normal and rosetted dormant apple twigs was also determined by Morris and here again the nitrogen content of the rosetted twigs was found to be higher than that of healthy twigs. With the reduced twig growth on rosetted trees and the consequently greater soil area per twig to draw on during the summer, when twig growth has ceased, it is not surprising that they accumulate larger supplies of nitrogen.

In the present studies on tobacco frenching we have shown that after a tobacco plant frenches nitrogen may be added at ten day or two weeks intervals in sufficient quantities to stimulate growth but not bring about recovery, or a slightly larger amount may be added at one time may bring about recovery in the course of a few days. The recovery may be very temporary,

as the stimulation to growth by the addition of nitrate increases carbohydrate production and in the presence of sufficient water the plants soon increase their demand for nitrogen, use up that added and have a larger demand on the soil than previously. The addition of more nitrogen may again bring about recovery which is temporary or permanent depending upon the amount added. It is evident that the plant must have a constant supply of readily available nitrogen in order to remain healthy.

In both the pecan and apple rosette studies the addition of nitrogen in the form of salts or dried blood has given negative or injurious effects. In neither case, as far as we have been able to determine from the literature, has an attempt been made to keep the trees supplied thruout the season and year after year with a sufficient supply of applied nitrogen. It would be of great interest to know what results Morris would have obtained had he continued applications of dried blood thruout several seasons as he states "The application of nitrate of soda, 300 and 500 pounds per acre, on four and five-year-old orchards, gave no improvement in rosette condition. Dried blood used at 500 to 1,000 pounds per acre *made a distinct improvement in tree growth* (italics ours) but did not cause rosette condition to disappear." The effects obtained by the addition of nitrate of soda and dried blood appear to be consistent with the nitrogen deficiency theory. Nitrate of soda is readily available and if applied early in the season would be expected to stimulate growth and possibly aggravate rosette; whereas the more slowly available nitrogen in dried blood might simply augment the natural supply of nitrogen over the entire growing period and thus tend toward a more normal growth. When the supply from dried blood was exhausted, the tree would have a greater demand for nitrogen than previously, and would be expected to again show rosette in a severe form. Whipple (21) showed that it would be necessary to add approximately 9,406 pounds of commercial nitrate of soda per acre to bring the nitrogen content of an orchard soil, under continuous clean cultivation for a period of 8 years, up to the content of a similar soil in clover

for the same period. In the former soil the rosette and die-back types of injury were common, in the latter they did not develop.

If we may compare conditions in our pots with orchard trees it must be evident that an application of 300 to 500 pounds of nitrate of soda per acre could have but little effect on nitrogen starved rosetted trees. In our experiments the addition of approximately 400 ppm. of NO_3 from various sources often resulted only in a temporary recovery lasting but a few days. The addition of 500 pounds of nitrate of soda per acre is at the rate of 182 ppm. of nitrate to the upper six inches of soil. The apple tree roots much deeper and consequently the parts per million added would, for the entire soil volume in which the tree feeds, be too little to bring about recovery even tho added regularly every two weeks thruout *the active growing period* of the tree, if the tree has requirements similar to those of tobacco. Even the addition of 9.406 pounds of nitrate of soda per acre, (Whipple 21) would only add nitrate at the rate of 543 ppm. in the upper three foot layer of soil, a quantity sufficient to bring about only temporary recovery in severely frenched tobacco plants which are growing rapidly.

The value of legumes as a means of adding nitrogen to the soil is well recognized. It is not surprising, therefore, that the growth of a deep-rooted legume like alfalfa would have the effect on apple rosette reported by Clawson (3). Nitrogen would be added not only in the upper layers of soil, but thruout the depth of penetration of the apple roots. A similar effect on bluegrass has been noted by Karraker (9) where bluegrass and sweet clover were growing in association, as compared with bluegrass from which all legumes were scrupulously excluded. In the association the bluegrass grew very luxuriantly whereas alone it made very little growth and appeared starved and yellow thruout the summer (Fig. 12). This experiment was conducted on the highly fertile "bluegrass soil" at Lexington. The effect in this instance would certainly be attributed to the addition of nitrogen rather than to any other factor and appears entirely comparable to the results obtained in the control of rosette of apples by the growth of alfalfa.

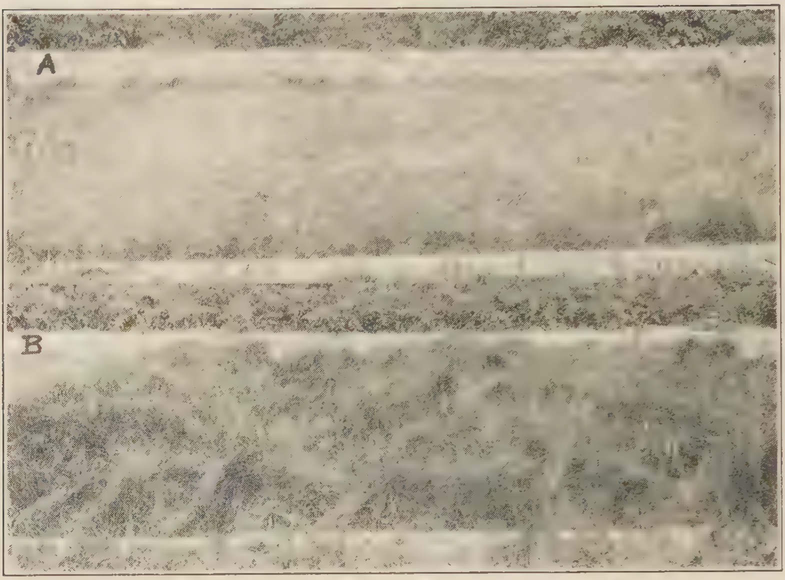

Fig. 12.—Effect of a legume on the growth of bluegrass. A. Bluegrass on the highly fertile "bluegrass" soil at Lexington, from which legumes have been excluded. B. An adjacent plot in which sweet clover was growing in association with the bluegrass. The bluegrass alone (A) showed nitrogen starvation while that in association with clover made a very rank, dark green growth. The sweet clover was cut in July and the photograph taken in the fall of 1925. Photos by curtesy of Prof. Karraker.

Altho much more thoro work is needed to determine the nitrate content of a soil necessary to prevent frenching, the results of the sand and soil cultures reported in this paper indicate that tobacco plants will continue to french in a limited volume of soil receiving 52 parts per million of nitrate every two weeks (summer) in addition to that produced by the soil, while the addition of 104 ppm. at intervals of two weeks, keeps the plants in a healthy, growing condition. In sand cultures the addition of 40 ppm. of nitrate did not prevent frenching but the addition of 80 ppm. at about 10-day intervals resulted in healthy plants. Morris found 73 ppm. of nitrate (16.5 ppm. of nitrate nitrogen), on an average, from July 24 to September 15, in a soil low in humus, in which the trees were healthy.

In the case of apple rosette Morris reports that the removal of all the healthy wood from diseased trees results in the develop-

ment of "water-sprouts in abundance and forced much of the affected wood into normal growth." The same type of results has been obtained with pecan rosetted trees (14, see Pl. XXVIII. Fig. 2) where a rosetted tree cut back to the stump made an apparently normal, very rapid growth the following season but developed rosette in the terminal growth of that season. They observed the same results following severe die back. These results correspond very closely to the results obtained with tobacco, where, if "frenched" soil is allowed to rest a few days and a small plant is set in it, it will make a normal, healthy growth for a time and then french. In other words, if the nitrogen requirement of the pecan or apple tree is reduced by heavy pruning, normal healthy growth will result until the requirement again becomes greater than the supply, when rosette will again result.

Tobacco grown in pots usually frenches soon after the first signs of nitrogen starvation become apparent in the lower leaves. Occasionally a few plants in a group will not show frenching of the growing point but will show chlorosis and death of the lower leaves, resulting in a rosette of leaves at the top of the plant; or this condition will often eventually result in frenched plants in pots. This is an evident case of nitrogen starvation as it is usually recognized. The close relationship between this condition and frenching in tobacco grown in the greenhouse has been pointed out. This condition of nitrogen starvation (Fig. 8A and B) corresponds very closely to the symptoms of apple rosette, as it occurs in the eastern part of the United States, attributed primarily to drouth conditions. This disease is characterized by a tuft of leaves at the tip of the current season's growth, the lower leaves having dropped off. The condition is prevalent in soils low in organic matter (and nitrogen) and low in soil moisture. The loss of the lower leaves in apple rosette is attributed to a lack of moisture ($_1$) but in the work with tobacco it has been possible to cause recovery of the green color in leaves which have become light yellow, except for a slight amount of green color about the veins, by the addition of nitrate, and by proper feeding prevent, both in the field and greenhouse,

the yellowing and death of any of the leaves on the plant thruout its growth. It seems certain in the case of tobacco that yellowing and death of the lower leaves during dry periods is not due directly to lack of water, but to a lack of nitrogen resulting from the effects of the drouth on the activity of microorganisms in the soil. It is possible that the addition of a constant adequate supply of nitrogen to rosetted apple trees might give results similar to those obtained with tobacco without any increase in moisture supply. In fact, this is done in Washington (3) where if alfalfa is grown in the orchard, recovery from rosette results in spite of the greater drain on moisture brought about by a cover crop.

It is of interest to note in connection with the drought theory of apple rosette that Morris makes a point of the fact that in the West, in orchards observed by him, rosette is most prevalent in portions of orchards which receive seepage water and are consequently wetter than other portions where healthy trees are growing. This is a common condition in portions of fields where tobacco frenching occurs, but frenching may occur in places where excess moisture is not a factor, thus being similar in this respect also to apple rosette.[8]

Mix (12) working in the Champlain Valley of New York has made extensive observations and done a limited amount of experimental work on apple rosette and various types of spotting in the flesh of apples. He states that Charles F. Brooks considers the rosette as it occurs in the east very similar to the disease as it occurs in the west. From the results of his observations, it seems quite certain that the fruit spots which he calls drouth spot and cork are closely related to rosette and appear to blend into the so-called bitter-pit or strippen spots. Mix has attempted to associate the rosette and die-back condition of apples and the accompanying fruit spots with dry periods and has done so in part. However, as he points out, during wet seasons when there appears to be no deficiency of water these diseases may still be present. In view of these facts, Mix con-

[8] The rosette of apples in the East (1, 12) appears to be a clear case of nitrogen starvation as it is usually recognized in plants, while the apple rosette occurring in wet places in the West corresponds with the frenching type of nitrogen deficiency as it occurs in tobacco.

cludes that "insufficient soil moisture cannot be looked upon as the sole cause. Some not thoroly understood factor or factors must operate to produce the disease under these conditions."

About fourteen years ago the senior writer did some histological and cytological work on stippen of apples and has been interested since in the various theories put forward in regard to its probable nature. None of the theories so far advanced seem to fit all conditions. In view of the striking relationship which Mix has shown to exist between apple rosette and the fruit spots, and because of the fact that rosette appears to result from nitrogen deficiency, is it not possible that these so-called drouth and cork spots may also result from temporary nitrogen starvation? The relationship between frenching of tobacco and drouth and cork spot of apples may not at first be obvious but if it is admitted that frenching is the result of an unbalanced nitrogen-carbohydrate ratio, then what would happen in an apple tree which, because of unlimited new soil to send its roots into, had made rapid growth for many seasons but because of roots of different trees growing together, was beginning to feel competition? This might occur during a growing season and be aggravated by a period of dry weather which would slow up or stop nitrification. If the tree had been vigorous the previous season and stored up a large supply of carbohydrates, it might readily produce a large new twig growth and set a crop of apples both of which might be growing rapidly. If the nitrogen supply were cut off by the conditions above mentioned so that the tree could not obtain a sufficient supply to retain the large leaf area and crop of fruit, a rapid adjustment must take place. Translocation of nitrogenous materials would probably take place from the lower leaves of the current season's growth toward the growing point, with the consequent appearance of nitrogen starvation or partial defoliation of the twigs, resulting in rosette; or possibly in more severe cases of starvation, actual dying back of the twigs might occur. In the case of the fruit, fleshy portions make a rapid vegetative growth and obtain a considerable size before embryo development progresses rapidly. There seems to be no good reason for believing that

tissue similar, as far as nutrition is concerned, to a frenched growing point of a tobacco plant, may not develop in the rapidly growing fleshy portion of the fruit. In other words, tissues largely made up of carbonaceous material might be laid down faster than they can be supplied with a balance of nitrogen, necessary for normal growth. If, then, conditions such as drouth developt, which limited the supply of nitrogen, and at the same time embryo formation was proceeding rapidly, there is reason to believe that the limited nitrogen supply would go to the seeds rather than to the partially starved flesh. In tobacco it has been pointed out that a growing point may continue to french while leaves behind it may recover gradually. Drouth and cork spots develop at the outer extremity of the fruit in a position comparable to a frenched growing point of tobacco. The supposition is that the tissue which develops drouth spot would theoretically be the last to be supplied with nitrogen, if there is a shortage, and as a consequence might die of nitrogen starvation. Necrosis of leaf blade tissue occurs occasionally in tobacco frenching and has been made the subject of considerable discussion by Rand (15), in the case of pecan rosette, where it occurs in the chlorotic areas of the leaf, so that it would not be surprising if necrosis also resulted in the fleshy portion of an apple.

The situation with respect to stippen or bitter pit is slightly different. The disease usually develops later in the season and often after harvest. A modification of the nitrogen theory seems, however, to apply. It is not unusual for apple trees to show signs of mild nitrogen starvation during the latter part of the season when the leaves, developing buds and growing fruits are all requiring nitrogen and when dry or excessively wet periods may be quite common, thus temporarily reducing the nitrogen supply for a longer or shorter period. Is it not possible that during these periods translocation of nitrogenous materials may take place from the flesh to the developing embryos, to the extent that cells of the flesh are injured in varying degrees, resulting in very slow death or more immediate death as the case may be? Translocation of nitrogenous materials within plants

is a recognized phenomenon. In the case of the spots which develop in harvested fruits, translocation may continue from the flesh to the seeds, resulting in stippen spots in storage.

Wickens and Carne (22) have recently shown that small immature fruits of the very susceptible variety, Cleopatra, are particularly susceptible to pitting when picked and kept at room temperature.

Apples of the same variety picked February 23, 1927, and kept in ordinary storage developed 18.3 percent of pit, while apples picked 15 days later developt only 5.1 percent under the same conditions, indicating that the longer a fruit has access to food material from the tree the less likely it is to pit. This, of course, does not prove that nitrogen is the factor concerned but it does suggest that food materials rather than water are concerned in pitting. Wickens and Carne further showed that terminal fruits developt a higher percentage of pit when picked before maturity than lateral fruits. If nitrogen is concerned in the problem, this condition might be expected, as the work with tobacco has shown that whereas a growing point may make rapid growth in the absence of sufficient nitrogen and become frenched, yet when the plant is gradually supplied with nitrogen the lowest frenched leaves are the first to be supplied, followed by those higher on the plant. The similarity between the recovery of the lower frenched leaves and the smaller amount of pitting in lateral fruits is evident. They further state that pit does not develop on either mature or ripe apples. Heinicke (7) has shown that apples grown on the terminal position of a fruit cluster have fewer seeds and are less likely to pit than laterally borne fruits on the same spur. He has further shown that irregular fruits, in which seeds are developt only on the larger side, usually develop pitting after harvest only on the side containing the seeds. He further showed that apples borne on weak wood are more likely to bitter pit than those on strong, rapidly growing wood, and states (p. 227) "In several cases sodium nitrate was applied to one side of Baldwin trees in sod, while the remaining portion served as a check. Fruit on limbs corresponding to the side receiving fertilizer showed less Bald-

win spot than apples on limbs which did not have the nitrate." This evidence, altho given for another purpose by Heinicke, is a striking confirmation of the nitrogen theory of the disease. In discussing the results obtained he states: "The disease may be regarded as a kind of drouth or starvation spot. . . . Failure to receive water and other nutrients which are needed to continue growth, or to mature tissue which has not entered its rest period might, for example, cause changes in the H-ion concentration of the cell sap. Such changes would affect enzyme activity, respiration and other metabolic processes. The result might be a disorganization of the protoplasm and subsequent oxidation of the affected tissue." In comparing the nitrogen theory of bitter-pit and the water relationship theories it should be remembered that changes in water content of the soil sufficiently great to affect the development of the plant will likewise have a marked effect on the soil micro-population and consequently on the nitrogen supply furnished the plant.

Certain facts in the work of Mix are definitely in favor of the nitrogen explanation of both rosette and the pitting of the fruit. He pointed out that during the summer of 1914, which was dry, the diseases (drouth spot, cork and die-back) were severe. The drouth in itself would retard nitrification markedly and, from several references to physical condition of the soils under consideration, conditions for nitrification were rather poor at best, as in some seasons the soil was so hard that cultivation was impossible. A dry spring in 1915 resulted in injury to the fruit, but a wet July and August resulted in little or no die-back. Also there was considerable evidence of recovery from preliminary stages of die-back, the twigs making a large amount of vigorous growth beyond the unhealthy part. With higher moisture content, nitrification could proceed continuously and further effects of nitrogen starvation would not be expected. Comparatively little direct evidence was given by Mix as to the part which nitrogen might play in the problem, but what was given is in favor of the nitrogen theory. He states: "In 1915, under comparatively clean culture, the disease (drouth spot) was quite prevalent in the shady parts of the orchard. . . .

In a small block of trees where the soil is the same, but where a crop of sweet clover was growing, cut and left as a mulch, the disease did not develop. The clean-cultivated parts of the orchard were seeded to alfalfa in August. In 1916 very little disease developt. It occurred to a very slight extent on six trees.'' In another instance, in an orchard which was badly diseased in 1915, red clover, together with a moist season in 1916, resulted in fruit free from drouth spot and cork.

McAlpine, (10) who has made a comprehensive study of bitter-pit of apples in Australia, was of the opinion that the disease was due to adverse water relations. A careful study of his extensive reports, however, leaves a question as to whether water is directly concerned or whether it merely influences some other factor of importance in the nutrition of the tree. In examining his reports, with the nitrogen theory of bitter-pit in mind, no facts presented were seriously opposed to it and a great deal of evidence given favored the theory. Conditions which brought excessive growth of trees, such as severe pruning, a liberal supply of water followed by a shortage, young trees making vigorous growth and an extensive, vigorous root system such as is developed by Northern Spy stock, all favored the development of the disease. Large, rapidly growing fruits were more susceptible than slower growing, small fruits. Rapid growth is dependent on an abundant supply of carbohydrates and of course an available supply of nitrogen. Early spring growth depends to a great extent on stored carbohydrates and perhaps largely on nitrogen stored the previous season. Following a period of rapid spring growth, the tree still requires a liberal supply of nitrogen for the proper development of leaf and fruit buds and embryos. If any conditions came about, such as drouth, which affect the nitrogen supply it may be expected that some of the tissues already laid down will not receive an adequate supply to maintain them. This appears to be the case in certain of the trees observed by McAlpine which produced pitted fruits. In certain of his photographs (see pls. X and XXII, 5th report) of trees which had made rapid growth and produced a crop of badly pitted fruits the trees show

marked signs of nitrogen deficiency as evidenced by the fact that the leaves have fallen from many of the current season's twigs leaving long whips with a tuft of leaves toward the outer extremity.* Photographs of trees which had produced a normal crop of fruit do not show this condition, but the trees appear to have retained most of their leaves. McAlpine did not study bitter-pitted apples with respect to nitrogen content but in a chemical study of the Jonathan spot, which is evidently of the same general nature as bitter-pit, he showed that the nitrogen content of normal and of spotted fruits was as follows (Rept. 5 p. 13):

Nitrogen content, normal whole apple—dry basis	.529
Nitrogen content, affected apple—dry basis	.339
Nitrogen content, normal skin—dry basis	1.092
Nitrogen content, affected skin—dry basis	.861

A study of total nitrogen in the soil in a fence row and in the adjacent orchard indicated that in the orchard the total supply had been much depleted. He reported that applications of nitrogen in the spring tended to aggravate the disease, a condition similar to that reported in this country for pecan and apple rosette. Stimulation of growth in the early spring could readily result in excessive growth and a nitrogen demand late in the season which could not be supplied by a soil which required artificial sources of nitrogen to maintain vigorous growth.

The theory of the relation of nitrogen to stippen and the more severe types of spotting can be readily tested, but in view of the results obtained in the control of tobacco frenching, where small applications of nitrogen may only stimulate growth without controlling frenching or may give only temporary relief, an effort should be made to bring about conditions such that

*Since this bulletin has gone to press, another application of the nitrogen theory of defoliation of fruit trees has come to notice, which is complicated by a bacterial disease and, consequently, appears to have been misinterpreted. This is the defoliation of peach trees, usually attributed to **Bacterium pruni**. The **Bacterium pruni** situation, as viewed from the standpoint of nitrogen starvation, may be summarized as follows: **Bacterium pruni** in itself will not cause defoliation, it being a manifestation of nitrogen starvation. When leaf-dropping is occurring, there is no relationship between spotting and dropping; dropping beginning with the lower leaves of the current season's growth and proceeding upward without respect to leaf condition. Trees supplied with a **constant adequate** supply of nitrogen thruout the season do not defoliate, even tho the leaves are riddled with spots. In Kentucky, in a few orchards, the nitrogen demand of peaches is being met by growing legumes in the orchard, and in at least one orchard it is being met by heavy manuring. In each of these cases **B. pruni** is controlled nearly completely.

the available nitrogen supply will be sufficient to supply not only the partially starved trunk and branch tissue but to supply any tissues, as twigs and young fruits, which are developt as a result of carbohydrates stored the previous season, or to supply tissue developt in periods of very favorable growth, followed by unfavorable conditions. Manuring, growing sweet-clover or alfalfa, turning under legumes, or the application of readily available nitrogen compounds at intervals thruout the season for several seasons, should meet the requirements.

The evidence for rosette and die-back of apples and pecans, and frenching of tobacco being diseases of a similar nature, appears quite strong. There is another disease of apples and other fruit trees that has so far remained unexplained, but which may fall into this general group of nitrogen troubles. This is the brown bark spot disease of apples, pears, plums, etc., occurring in Montana (18). This disease is not prevalent in Kentucky, but occasionally specimens have been received which appear very similar to it. In April, 1923, specimens of Rome Beauty twigs were received from Mr. Fred C. VanHoose, of Johnson County, which showed the round dead areas in the bark characteristic of brown bark spot disease. The disease in these trees is of a mild type and does not cause die-back.* A little later, specimens of Rome Beauty were received from Crockett, Morgan County, which showed the brown bark spots and dead buds. In the fall of 1926, specimens were received from County Agent William Johnstone, Paducah, Kentucky. They were from trees about three years old, which for the past two seasons, 1925-26, had received heavy applications of farm manure. They started into vigorous growth in the spring of 1926, but during the summer became defoliated, the new growth died back to quite an extent, and pimples and dead spots developt on the bark. Specimens were sent to Professor Swingle, of the Montana Experiment Station, asking whether they were brown bark spot or not. He replied (November 4, 1926) "I doubt if this disease is the same as our brown bark spot. In the case of our disease the

*The past winter, since the above was written, some of these trees have developed quite extensive dieback.

leaves do not come out and then drop, but the buds are so affected in the spring that they produce no leaves. Hence certain branches are defoliated from the beginning of the season. These affected branches make little or no attempt at growth, and often die before autumn. I quite agree, however, that the appearance of the bark is closely similar to our brown bark spot." The close similarity of the bark of these specimens to the bark of trees affected by brown bark spot and the fact that both lead to a die-back condition, suggest that they are identical troubles, but brought about by somewhat dissimilar conditions and therefore are manifested slightly differently. The reason for believing that lack of nitrogen may have been the factor in causing the disease at Paducah is that the spring of 1926 was dry, but not so dry in the early spring as to prevent rapid growth in healthy trees. The drouth continued until late in June, the soil becoming very dry over most of the western part of the State. Under these conditions the nitrogen supply may have been very low. If certain trees were unable to obtain sufficient nitrogen to maintain the large amount of new growth developt, it is natural that an adjustment must occur in the plant which might result in the death of the tender new shoots and possibly also of areas in the bark of the older growth. Whipple (21) in studying the growth of fruit trees under various systems of culture in Montana, showed that the group of die-back diseases of which brown bark spot and rosette appear to be examples, developt severely under a system of clean cultivation; to a less extent where intercropping with potatoes was practised and was not present where legumes were grown. He stated that "We believe the real cause is a deficiency in available plant food, probably nitrogen," (p. 115) and gave figures to show that the nitrogen content of the soil in the clean-cultivated orchards was far below that where legumes were regularly grown. Swingle and Morris (18) consider that these deficiencies may aggravate brown bark spot but do not seem to consider them the actual cause of it. They recommend, however, that special attention be given to increaseing the fertility of the soil.

Other diseases which have been considered as due to adverse water relations, but which might as readily be due to adverse nitrogen relations are straight head of rice and blossom end rot of tomatoes. In the straight head disease it has been determined that in virgin soils and soils which have grown non-irrigated crops for several years continued flooding after the rice is up results in straight head, whereas withdrawal of the water for a time results in recovery (19). Biological processes in the soil are evidently concerned, which may reasonably have to do with the available nitrogen. One of the characteristic symptoms of straight head is the production of a large system of primary roots with few secondary roots. Reid (16) in working with cuttings of tomato containing varying amounts of carbohydrates and nitrogenous materials, found that a high carbohydrate and low nitrogen cutting produced a plant with small, rigid shoots bearing stiff, yellowish-green leaves, and numerous, frequently unbranched roots which were usually not long. The description of the shoots and unbranched root system compares favorably with those produced in straight head. The deep green color in straight head may be due, as in old frenched tobacco plants, to a gradual accumulation of nitrogen as it becomes available.

Tomato blossom end rot might fall into the same category with cork and drouth spot of apples. It has been shown to follow periods when soil moisture content was low but it is hard to imagine conditions resulting from water relations within the plant, other than severe wilting of the fruit, which could produce the necrotic areas found in blossom end rot. Work, (25) in a study of the nutrition of tomatoes, described a condition of tomatoes growing in sand cultures, which had received a heavy application of nitrate of soda at the beginning of the experiment, which closely resembles frenching of tobacco. It is stated (p. 12) with regard to the high nitrate series "During the later history of G, H, and J, there was a marked yellowing of leaves and stems became so brittle that it was almost impossible to prevent accidental breakage in the course of necessary care," a condition nearly identical with that described by Reid in tomato cuttings containing high carbohydrate and low nitrogen

and is descriptive of frenching symptoms in tobacco. A chlorosis of the leaves between green veins is also described. The fruit on these plants were "affected in marked degree with blossom end rot." "These plants had suffered somewhat from wilting ever since they were planted," the blossom end rot being attributed to this condition. Plants receiving smaller applications of nitrate of soda showed marked signs of nitrogen starvation and did not develop blossom end rot. That the condition described could be similar to tobacco frenching and that there could be signs of nitrogen starvation in the plants receiving a high application of nitrate of soda does not at first seem plausible, but Work pointed out that after a few waterings the concentration at the bottom of the box became greater than at the top, due to leaching, and that the roots did not penetrate this concentrated zone. Following heavier applications of water, blossom end rot disappeared, and it was assumed that the disappearance was due to no further wilting. In set S (p. 47), in which 36,096 pounds of nitrate of soda per acre basis were used, 33 ppm. of nitrate were present in the upper third of the sand, 221 ppm. in the second third and 5,231 ppm. in the lower third. The roots were nearly all in the upper half of the sand. Wilting may have resulted from a small root system in the "high application" series and not to a high concentration of salts about the roots as was assumed. If the watering were such as to keep the plants near the wilting point at all times, it is not likely that much nitrate could rise to the zone in which the roots were functioning, and thus in the apparent presence of an abundance of nitrate, nitrogen starvation might actually occur. A raise in moisture content of the sand stopped wilting and checked blossom end rot. It was assumed that lack of wilting was due to greater dilution of the salt solution, but from the figures presented it is more probable that it was merely due to the addition of an adequate water supply for the large plants. In view of the concentration of nitrate in the bottom layer of sand, is it not likely that the addition of larger quantities of water increased, rather than decreased, the concentration of salts in the upper

layer both by the greater tendency to establish an equilibrium, with more water present, and to capillary rise of salts as the upper layers became dry? Thus control of blossom end rot might as readily be explained on the basis of increased nitrogen as on a change in water relations. That the plants did receive more nitrogen with the addition of larger quantities of water is suggested by the statement that near the close of the experiment these plants showed a marked tendency to develop new branches, some of which promised to make a more normal growth," a picture resembling recovery shown in our Fig. 4B.

Brooks (2), in studying blossom end rot of tomatoes, produced evidence to show that "excessive dryness is not essential to its development for plants that produce most rot never wilted." Much of the evidence presented strongly suggests that the factor influenced by the various conditions of his experiments was not moisture but may have been nitrogen. Temperature of the water used on the plants influenced the disease. The addition of straw, sphagnum and fresh horse manure increased the disease. Plants forced with fertilizers were more susceptible, but "increasing the application of sodium nitrate tends to decrease rather than increase the disease." Nitrogen furnished in the form of ammonium compounds appeared to favor the disease.

Altho the arguments presented, with respect to the fruit spot diseases and blossom end rot, do not prove that these diseases are caused by a shortage of nitrogen, yet if they serve to turn attention from the very improbable water relation theory to a study of nitrogen relations in these and similar diseases a purpose will have been served.

SUMMARY

1. Frenching of tobacco is a disease characterized by chlorosis of the leaf tissue between the veins or, in severe cases, the entire growing point may be chlorotic.
2. The disease has been repeatedly produced in the greenhouse by growing turkish tobacco plants in ½ gallon jars of virgin soil from a hard-wood forest on the Experiment Station grounds.
3. In pot experiments the disease usually appears in the growing point at about the time nitrogen starvation begins to appear in the lower leaves. It is readily controlled by the addition of nitrogen to the soil in any of the readily available forms as $NaNO_3$, KNO_3, urea, ammonia compounds, etc. Control will extend over a

long time or be short lived, depending upon the amount of nitrogen added.

4. Pecan rosette, apple rosette, frenching of citrus and certain other chloroses present aspects so similar to frenching of tobacco as to suggest that they are diseases of the same nature.
5. The disease is not transmitted by grafting. Frenched scions, if put on healthy plants, soon recover.
6. In pot experiments plants set during the winter french at a later stage of development and require a longer time than plants grown in the summer. Single plants or several plants set in a pot at the same time will french nearly simultaneously. The dry weight of the tops of single plants and the total of the several plants will be about the same at the time frenching occurs.
7. Fifty-two parts of NO_3 per million of air-dry soil added every two weeks to soil in which plants were beginning to show nitrogen starvation was not sufficient to prevent frenching, while with the addition of 104 parts per million at the same intervals the plants became dark green and did not french.
8. Frenching has developed in sand cultures soon after the plants showed signs of nitrogen starvation. The addition of 40 parts of NO_3 per million of dry sand was not sufficient to result in healthy plants while the addition of 80 parts per million resulted in a healthy, dark green growth.
9. Heating the virgin soil to 65 degrees C has the same effect on the growth of tobacco plants in pot cultures as the addition of available nitrogen; the plants grow much larger before showing signs of nitrogen starvation than when grown in the unheated soil, and usually do not french, even after nitrogen starvation becomes prominent. Only one plant has frenched in heated soil.
10. CaO added to virgin soil in large quantities stimulated growth of tobacco plants over those in untreated soil and appeared to prevent frenching altho nitrogen starvation eventually developed in the lower leaves. The stimulation was much less than that resulting from heating the soil to 65 degrees C. A second crop of plants grown in the same soils developed slightly better in the untreated soil but the plants soon frenched. Those in soil to which CaO had been added grew more slowly, and developed nitrogen starvation in the lower leaves at about the same time as the others but gradually outgrew them and did not french.
11. Control of frenched tips of tobacco may be brought about by rooting the tips in sand by layering, and supplying nitrogen to the tips thru the roots in the sand. The growing point will recover while suckers developing from the base of the plant and obtaining nitrogen from the soil continue to french. This experiment demonstrates more clearly than by addition of nitrogen to soil that the problem is purely one of nitrogen supply.
12. Evidence is presented which suggests strongly that drouth spot, cork spot and bitter-pit of apples and blossom end rot of tomatoes are diseases of the same general nature as frenching and are due to nitrogen starvation of the affected tissues.
13. The theory is advanced that brown bark spot of apples and other trees is a disease due to nitrogen starvation.

LITERATURE CITED

1. Adams, J. F. Dieback and Apple Tree Rosette. Reprint from Trans. Penn. Hort. Soc. 1922, pp. 1-9.
2. Brooks, Charles. Blossom-end Rot of Tomatoes. Phytopathology, IV, 345-374, 3 pl. 5 fig. 1914.

3. Clawson, O. T. Rosette and Cover Crops. Better Fruit. 10, No. 10, pp. 24-25. 1916.
4. Clinton, G. P. Chlorosis of Plants with Special Rerefence to Calico of Tobacco. Connecticut Agr. Exp. Sta. Rept. 1914, 357-424.
5. Floyd, B. F. Some Cases of Injury to Citrus Trees Apparently Induced by Ground Limestone. Florida Agr. Exp. Sta. Bul. 137, 163-179. 1917.
6. Garner, W. W. Tobacco Culture. U. S. Dept. of Agr. Farmers Bul. 571, 1-24. 1922.
7. Heinicke, A. J. The Seed Content and the Position of the Fruit as Factors Influencing Stippen in Apples. Proc. Am. Soc. for Hort. Sci. 1920, 225-232.
8. Johnson, James. Tobacco Diseases and Their Control. U. S. Dept. of Agr. Dept. Bul. 1356, 1-56. 1924.
9. Karraker, P. E. Note on the Increased Growth of Bluegrass from Associated Growth of Sweet Clover. Jour. Am. Soc. Agronomy, 17: 813-814. 1925.
10. McAlpine, D. Bitter Pit Investigation. Progress Reports 1-5, 1911-1916. Albert J. Mullet, Government Printer, Melbourne.
11. McMurran, S. M. Pecan Rosette in Relation to Soil Deficiencies. U. S. Dept. of Agr. Bul. 756, 1-11. 1919.
12. Mix, A. J. Cork, Drought Spot and Related Diseases of the Apple, N. Y. (Geneva) Agr. Exp. Sta. Bul. 426, 473-522. 1916.
13. Morris, O. M. Apple Rosette. Washington Agr. Exp. Sta. Bul. 177 (Technical), 1-30. 1923.
14. Orton, W. A. and Frederick V. Rand. Pecan Rosette. Jour. Agr. Rsch. 3, 149-174. 1914.
15. Rand, F. V. Pecan Rosette: Its Histology, Cytology. and Relation to Other Chlorotic Diseases. U. S. Dept. of Agr. Bul. 1038, 1-42. 1922.
16. Reid, Mary E. Growth of Tomato Cuttings in Relation to Stored Carbohydrate and Nitrogenous Compounds. Am. Jour. of Botany XIII, 548-574. 1926.
17. Skinner, J. J. and J. B. Demaree. Relation of Soil Conditions and Orchard Management to the Rosette of Pecan Trees. U. S. Dept. of Agr. Bul 1378, 1-16. 1926.
18. Swingle, D. B. and H. E. Morris. The Brown Bark Spot of Fruit Trees. Montana Agr. Expt. Sta. Bul. 146, 1-22. 1921.
19 Tisdale, W. H. and Jenkins, J. M. Straighthead of Rice and Its Control. U. S. Dept. of Agr. Farmers' Bul. 1212, 1-16. 1921.
20. Valleau, W. D., P. E. Karraker and E. M. Johnson. Corn Root-Rot, A Soil-Borne Disease. Jour. Agr. Rsch., 33, 453-476. 1926.
21. Whipple, O. B. Report of the Work of the Horticultural Substation. Montana Agr. Exp. Sta. Bul. 114, 101-123. 1916.
22. Wickens, Geo. W. and W. M. Carne. Bitter Pit in Apples. Its Occurrence in Store in Relation to Dates of Picking. Jour. Dept. Agr., West Australia, 4 (Sec. Ser.), 354-357. 1927.
23. Wolf, F. A. and S. G. Lehman. North Carolina Agr. Exp. Sta. 47th Ann. Rpt., 82. 1926
24. .Wolf, F. A. and Moss. Diseases of Flue-Cured Tobacco. The Bulletin North Carolina Dept. Agr. 40, No. 12, 1-45. 1919.
25. Work, Paul. Nitrate of Soda in the Nutrition of the Tomato. Cornell Univ. Agr. Expt. Sta. Memoir 75, 1-86. 1924.